NORTON'S STAR ATLAS

AND TELESCOPIC HANDBOOK

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8000 STARS, CLUSTERS, NEBULÆ, &c.,
AND LISTS OF 500 INTERESTING OBJECTS

NORTHERN INDEX MAP

Luminosity: Surface Brightness.—The luminosity of a star differs from its magnitude in being the *actual* amount of light emitted by the star, instead of the apparent amount, judged by its brightness to the eye. It depends on the star's diameter and temperature, being the star's area (actual, not angular) multiplied by the amount of light it emits per square centimetre, or other unit—*i.e.*, by its *Surface Brightness.* The Sun's surface brightness is taken as mag. 0, and a star's relative surface brightness, + or −, is expressed in magnitudes (Table, p.viii)—symbolised by *J.* The luminosity relatively to other stars is given by the absolute magnitude, or luminosity at 10 parsecs distance.

The higher the temperature, the greater the surface brilliancy; thus stars of the same absolute magnitude may differ greatly in size and surface brightness, for a low-temperature 'Giant' (p.20) must have a larger diameter than a high-temperature B-star, to be of the same absolute magnitude. From this relationship the diameter of stars can be calculated, independently of their distance, from the visual magnitudes, the surface brightness being obtained from the Type. The diameters that had been predicted on this basis were found to agree closely with the observed values.

Star-classification by their spectra.—Secchi in 1863-67 found that when the light emitted by different stars was analysed by the spectroscope, their spectra fell into four well-marked groups which graded into one another. In 1874, Vogel modified Secchi's scheme by adding two subordinate classes to Class I; another (Wolf-Rayet stars), to Class II; and including his third and fourth types as sub-divisions of the same order. Secchi's Types are now little used, except historically, but for very uncertain cases the I.A.U. defines them as follows (O5 was formerly Oe):—

TYPE I. O5-F5, predominant hydrogen lines. | TYPE III. M, titanium oxide bands. | TYPE V. Oa-Od, bright Wolf-Rayet lines.
„ II. F8-K5, prominent metallic lines. | „ IV. N and R, carbon bands.

About 1890, Pickering introduced the 'Harvard' classification, now universally adopted, lettering Secchi's original groups, with others, as in the table opposite, the various sections being spoken of as Type O, Type B, &c. Gradations or intermediates are indicated by combinations of the letters with figures denoting tenth parts. Thus B2 (a convenient abridgment for B2A) denotes a spectrum nearly like that of Class B, but estimated to be two-tenths of the way from B to the following Class A: and O5 (=O5B) means five-tenths of the way from O5 to the next Class, which is B, as Types W, O, are first in sequence—the original order was A, B, C, &c., but from later information it was altered, and some unneccessary letters dropped. Secchi's classes were based on visual, the Harvard on photographic, spectra, but on the whole they are fairly accordant. Type R was added 1908; S, 1922; W, 1935 (I.A.U., recommended).

B0 is the highest of Class B (the '0' is a starting cypher, not a letter), and the sequence is O8, O9, B0, B1, B2, B3, . . . B9, A0, A1, A2, &c.; the scale is thus a descending one. Sub-divisions a, b, c, &c., are used where there is uncertainty as to the details, but numbers are substituted when the necessary information is obtained: 'c' and 'n' stars, however, are not subdivisions, but stars having 'c' or 'n' characteristics (p.19). Variable stars are now classed at maximum (1922). For the sub-divisions included in a 'Type' when used in the average sense, or in statistical work, see next page. For details of Types O to N, see *H.A.*, Vol. 28; *H.C.* 145; and *Draper Catalogue*, 1924 (*H.A.*, vols., 90-99).

Early and *Late Type* stars denote Types B-A, and K-M, respectively, somewhat inconvenient survivals, in certain respects, of Vogel's assumption that Type I stars were the youngest, and Types III and IV the oldest, before the Giant and Dwarf divisions (p. 20) were known. For the same reason, the *Main Sequence* is the downward progression of increasing redness, O, B, A, F, G, K, M—Types R, N, branching off at G; and S, perhaps, at K5 or M0. Type W may be the last stage of another sequence from Nova through planetary nebula to join Type O at the other end.

Russell Diagram:—This shows very effectively the Giant and Dwarf relationship and the Main sequence, the stars being plotted according to Type (temperature), and absolute magnitude (luminosity). By adding curves representing masses, the Diagram has been extended to exhibit the mass-luminosity relationship as well.

Star Colours.—Colour is an index to physical condition and temperature (p. 21). A list of the mean colour of each Type, and sub-division, is given in Monthly Notices Royal Astron. Society, Vol. 84, p.22. Oa to Oc are given as greenish yellow; B2, B3, white; A0, pure yellow; A5, yellow; K2, orange yellow; M0, orange; R, orange red; Nc, deep orange red: intermediate types merge into the next colour. Colour also affects twinkling, as explained on page 38. The components of many double stars exhibit the curious phenomenon—sometimes merely optical—of being complementary in colour—orange and blue, or crimson and green, &c: for examples, see Notes Star Charts.

Relative Numbers of different Types (Shapley)—Of the 225,000 stars, to about mag. 10, in the Draper Catalogue, only some 2000 are of other types than B, A, F, G, K, M. Nearly 60,000 are brighter than about mag. 8½: 20,000 are essentially identical with the Sun, and 95 per cent are probably within 3000 light-years of us. A and K are most common in the Milky Way.

Type ...	O	B	A	F	G	K	M	N	R	S
Types included ...		*(B0-B5)*	*(B8-A3)*	*(A5-F2)*	*(F5, G0)*	*(G5-K2)*	*(K5-M8)*	...	...	...
No. of Stars		3,567	64,259	21,120	46,552	73,208	13,864			
Percentage; to Mag. 6¼ ...		10·9	30·5	10·4	9·9	30·1	8·1	...	...	...
„ „ „ 8¼ ...		2·5	26·7	11·0	16·7	35·4	7·6			

The Harvard (Draper) Spectral Classes.—The Table below gives the salient features*: the Roman numerals indicate Secchi's Classes (p. 18). The temperatures are those for a 'black body' (p. 21), and are more or less approximate, those below Type G (Sun = G0) being probably rather low. For the Radial velocity of each Type see page 21. Be, Me, Se, Oe, &c., stars denote B, M, S, O, &c. stars having bright emission lines (see p. 23).

'Type B,' 'Type A,' &c., when used in the general sense, or in statistical work, does not usually mean the series B0 to B9, or A0 to A9, but an *average* Type, in which A0, B0, &c., are approximately central, including the latter half of those lettered in the Type earlier, just as '2nd. magnitude' is not 2·0 to 2·9, but 1·5 to 2·5, or 1·6 to 2·5. Shapley's Table, opposite, indicates an (approximate) usual basis, but there is no definite rule: some begin Type B with O5.

VI. Type W. Wolf-Rayet Stars (at present in Type O). Continuous spectrum with many strong emission bands due to atoms of high ionisation potential: most important *He.* I, II, associated in a nitrogen sequence with *N* III, IV, V (Type W); or in a carbon one with *C* II, III, IV (Type W') *O* II, III, IV, V: typical stars, W5, H.D. 187,282, W6, 16,523. (See *Trans., I.A.U.* 1938.)

V. Type O. Wolf-Rayet Stars (Greenish-white). Very high temperatures, large masses and velocities: bright bands in their spectra indicate connection with planetary nebulæ and final stage of Novæ. All in Milky Way, or Magellanic Clouds. Subdivisions Oa, Ob, Oc, Od (Wolf-Rayet stars proper); and Oe, abolished 1928, O5-O9 being substituted, with Wolf-Rayet bands described by affixing a, b, c, d, as Oeb. (35,000° K., 62,000° F.). *γ Velorum.*

I. Type B. Orion or Helium Stars (Bluish). Helium lines prominent: very brilliant and hot: large masses; mean density 1/10th Sun's. Very distant: small proper motions and mean velocities: strong Galactic concentration; brightest mostly belong to Local Cluster; great globes of glowing gas. (25,000° K., 44,000° F.). *ε* (B0), *δ*, *ζ Orionis*; *β Crucis.*

Type A. Sirian or Hydrogen Stars (White). Balmer Hydrogen lines very intense, Helium absent. Most numerous Type after K. Predominate in low galactic latitudes. Greater proper motions than B. (11,000° K., 20,000° F.). *Sirius* (A0), *α Andromedæ*, *β Carinæ.*

Type F. Sirian-Solar or Calcium Stars (Yellow-white). Calcium H and K lines very prominent: Hydrogen lines much less intense, metallic lines increase. Much less numerous than A, but includes majority of known binaries, and large-proper-motion stars; little Galactic concentration. (7500° K., 12,200° F.). *Canopus* (F0), *γ Bootis*, *α Hydri.*

II. Type G. Solar Stars (Yellow). Hydrogen lines narrower and still less intense; H and K calcium lines prominent, and many fine, dark lines in spectra. Density of Dwarfs about 1½ times that of water. Move more rapidly than preceding types. Little Galactic concentration. (6000° K., 10,000° F.). *Sun*, *Capella*, (G0); *α*¹ *Centauri*, *β Hydri.*

Type K. Arcturian or Red-Solar Stars (Orange-yellow). Hydrogen lines fainter, hydrocarbon bands appear; density of Giants about 1/10,000th Sun's: most numerous type, predominate on the whole in low galactic latitudes. (4200° K., 7000° F.). *Arcturus* (K0), *α Ursæ Maj.*; *α*, *β*, *Indi.*

III. Type M. Antarian Stars (Orange). Spectra like that of the Sun, but with broad titanium oxide and calcium bands or flutings. Density of Giants less than 1/20,000th of Sun's; of Dwarfs, greater than Sun's. Very distant: higher mean velocities than B to K, in all directions; widely scattered. Fainter stars show a preference for the galactic centre (Sagittarius region). Sub-classes were Ma, Mb, Mc, Md (bright lines): Md was abolished 1922 (the 'emission' sign 'e' suffices), the others were made M0, M3, M8. (3000° K., 4900°F.). *Betelgeuse* (M0), *Antares*, *Mira.*

IV. Type N. Carbon Stars (Deep orange-red). Peculiar band spectra like those of comets and candle-flames, due to carbon compounds; two-thirds in or near Milky Way. Probably in a branch sequence, G, R, N. Sub-classes Na, Nb, (made N0 and N3, 1922), and Nc, the deepest red of all the stars (as *S Cephei*). (2600° K., 4200° F.) *Y Canum Ven.*, [*U Hydræ*, *19 Piscium.*

Type P. Used for gaseous nebulae. *(For details see H.A., vol. 28).*

Type Q. Used for Novae. Divided meanwhile (1928) into Qa, Qb, Qc, Qd, Qu, Qx, Qy, Qz; the last has weak Wolf-Rayet bands, but, unlike those before it, no bright hydrogen lines. (See page 42; and *Trans. I.A.U.*, 1922, 1928).

Type R. (Orange-red). Carbon bands; visually resembles N, but photographically different, blue and violet being brighter; not so red as M or N: brightest, mag. 7. Probably joins main sequence at G, the branch sequence being G, R, N. Added 1908 (*H.C.* 145); mostly in N previously. (2300° C., 4500° F.). *B.D.* −10° *5057* (R0), *C.D.* −24° *12084.*

Type S. Red stars. Mostly long-period variables; very complicated spectra, bright hydrogen lines, absorption and emission lines, and some zirconium oxide absorption bands; perhaps a branch from K5 or M0. Added 1922; mostly in N previously. (See a list *Mt. W. Contr.* 252). ... ... *π*¹ *Gruis*, *R Andromedæ*, *R Cygni*

Notation for Peculiarities.—There are two sets of notations, one prefixed, the other affixed to the Type; 'earlier' means in the Type B direction'; 'later', in the M direction. (The letters may be combined, as O6k.)

Prefixed. (See full list and details *Tr. I.A.U.*, 1922, 1928).

c All lines normally narrow and sharp (p.20); later than B0, hydrogen lines and enhanced lines abnormally strong.

g Giant Stars. Enhanced lines fairly strong; low-temperature lines relatively weak; hydrogen lines strong.

d Dwarf Stars. Enhanced lines weak, some calcium & titanium lines strong.

('c' Not used earlier than B0; 'g' and 'd' than F0.)

Affixed.

e Bright emission lines, except in P, Q: remarkable, e!

eq *do.* ; with absorption line on the violet side.

er *do.* ; bright lines conspic'sly 'reversed', dark centre.

em Bright hydrogen & fairly conspicuous bright metallic lines.

Affixed—*contd.*

ew Wolf-Rayet emission lines or bands: conspicuous, ew!

k Stationary hydrogen and calcium lines.

n Lines unusually wide or diffuse.

p Peculiarities: symbol of the element most affected in.

! Remarkable. [parenthesis: unidentified lines 'Un.').

q Absorption line on the violet side (with e).

s Lines sharp, but 'c' characteristic not present.

v Indicates a variable spectrum.

[ ] Forbidden lines; symbol of element in square brackets.

* Types C, D, E, &c., of the original scheme were found redundant.

Giant and Dwarf Stars.—Spectral type indicates the temperature; temperature regulates the surface brightness; and the surface brightness of a star multiplied by its area gives the luminosity or total amount of light emitted. This, again, regulates the absolute magnitude. Hence, when two stars of similar Type have different absolute magnitudes, they must have different light-emitting areas, and diameters. This is well shown on a *Russell Diagram* (*p.18*).

Analysis of absolute magnitudes shows that on the one hand there is a continuous series of stars from Types M to B, with increasing temperatures, which have great and fairly constant absolute magnitudes, ranging from about +1·0 to −2·0, or about three magnitudes. On the other hand there is a reversed series from A to M, with decreasing temperatures, and absolute magnitudes falling off a magnitude or two as each successive Type below is reached.

Stars of the increasing-temperature series are known as *Giants*, those of the decreasing-temperature one as *Dwarfs*, because the Giant M-stars must have enormous diameters to appear as bright as they are with their low temperatures, while the Dwarf M-stars must be small in diameter to appear as faint as they are, with similar temperatures. These names, however, only apply literally to the M or late K stars of the two branches, as the difference in diameter between each branch continually lessens with each step forwards or backwards towards A and B, until, in these Types, the members of each series cannot be distinguished: from F0, however, Giant and Dwarf stars are known by their 'enhanced' and 'low temperature' lines (p. 25), the Giants having a lower temperature than the corresponding Dwarfs, which are bluer. The Dwarfs greatly out-number the Giants; the cooling stage probably lasts much longer.

Super-giants are about 1000 times brighter than the Sun, with absolute magnitudes greater than about −2·0, like *Betelgeuse*; mean *M* (abs. mag.) about −2·7. *Sub-giants*, a well-marked group, average about 10 times the Sun's brightness, with mean $M = +2{\cdot}3$.

The *White Dwarfs*—exceptional stars like the companion of *Sirius* (*Sirius B*)—are stars of high temperature, yet so very faint, in proportion to their distances, that their diameters must be of planetary size, and their average density almost incredible—some of them millions of times that of water, their largely electron-stripped atoms being packed enormously closer than in the matter we know (see below). Being so faint, only the nearer ones can be seen.

Stellar Evolution.—These facts suggested the Hertzprung-Russell theory, that a star begins its visible life as a diffuse low-temperature M-giant. In accordance with 'Lane's Law'—that a gaseous body radiating heat, and contracting under its own gravity, must get hotter as long as it behaves as a perfect gas—the star gradually rises in temperature, and so passes into successive higher Types. At last a Type is attained—determined by its mass (see below). —at which radiation balances the energy supplied by contraction, and the star therefore begins to cool, and, entering the ranks of the Dwarfs, passes downwards through the same Types again to invisibiliy.

This theory, while it offers a very simple explanation of the Type-gradations, by no means explains all the facts, and from the phenomena of Novæ and White Dwarfs, it is now suspected that change of Type may be of a catastrophic nature, due to the collapse of a star.

Mass-Luminosity Law.—If stars are plotted according to mass and absolute magnitude (luminosity) they lie along a smooth curve on the whole, mass ÷ luminosity being practically a constant (except White Dwarfs). This *mass-luminosity* relationship enables star masses to be approximately calculated from the apparent magnitude and luminosity. A star's mass seems to determine its temperature, for only those of great mass attain Type B, and those of very great mass Type O. It now seems certain that as a star grows older its mass decreases, mass being converted into energy.

Period-Luminosity Curve.—Many stars vary in brightness, some irregularly, others in more or regular periods A certain type of these, known as Cepheids (p. 12), have the peculiarity that those of a given period have practically the same absolute magnitude (luminosity); the longer the period, the greater the absolute magnitude. The visual magnitude of a Cepheid star, of known period, will therefore give its distance. This property of Cepheids is of great importance in measuring the distance of extra-galactic objects, but the reason for it is not yet known.

Star Masses are only known directly in the case of binaries, the average binary system having about 1·8 times the Sun's mass (contracted, 1·8 ⊙); halving this, gives the average individual star mass as 0·9, or nearly that of the Sun The mass of non-binary stars is roughly calculable from mass and luminosity, see above.

Masses five or six times that of the Sun are not common, and no mass less than that of Kruger 60B, 1/6th of the Sun's, is known. The greatest known masses are the components of a mag. 6 O8 binary, *Plaskett's Star* (*H.D.* 47,129, combined absolute mag. −6·3), at least 158 and 113 times the mass of the Sun.

Star Densities.—Those of Giant M-stars are very small, less than that of air, being only some 1/10,000th to 1/20,000th of that of the Dwarf Sun, which is 1·42 times that of water; *Antares* has no greater average density than the vacuum in an electric bulb. To make up, their diameters are of the order of 100 to 500 million miles (see p. 21).

The White Dwarfs are at the other extreme; *Van Maanen's Star*, absolute mag. (visual) 14·4, is found to be about the size of the Earth, and some 300,000 times as dense as water—20 tons per cubic inch. A.C. +70° 8247, a 13th mag. O0 star, is half the size of the Earth, and 36 million times denser than water = 620 tons per cubic inch!

Star Temperatures.—Spectral Type is chiefly a temperature phenomenon, and stellar temperatures can be measured by analysis of the 'energy distribution' in their spectra—that is, by ascertaining the point at which the intensity is greatest: the further the maximum intensity is towards the violet end, the higher is the temperature.

A star temperature so found, however, is not that of the interior (which in the Main Sequence is of the order of 30 million degrees K.), or of the surface, but is what is called the *Black Body* or *Effective Temperature*, which may be defined as the temperature of a 'perfect radiator' (say that of a sheet of lampblack, the nearest approach to it) which sends out the same amount of radiation per unit of area as that emitted by an equal area of the star. This is based on 'Stefan's Law'—viz., that the total radiation is proportional to the 4th power of the absolute temperature (see below), multiplied by a constant depending on the nature of the radiating surface. For the approximate effective temperatures of each Type, see p. 19. The White Dwarfs have central temperatures of the order of 15 million degrees K; the M Giants, only a few million degrees K. The lowest effective temperature known is about 2000°K.

The Colour Temperature of a star is determined from the *distribution* of intensity in the continuous background between the lines of its spectrum: it is always higher than the effective temperature based on the total radiation; the difference increases with the temperature. The average Colour temperature of the A0 stars (18,000°K.) is the zero.

The Absolute Temperature is the temperature above *Absolute Zero*, the temperature of a gas containing no heat, −273°C. (−460°F.), usually stated in degrees 'K' (Kelvin), which is the ordinary Centigrade temperature *plus* 273° C.

To convert K° into Centigrade degrees, subtract 273°; into Fahrenheit,* multiply by 9, divide by 5, and subtract 460°.

Opacity and Radiation Pressure are factors of great importance in the theory of stellar interiors. The first is the resistance of the gaseous material to the outward flow of radiation—hydrogen, the lightest element, offering least resistance; the opacity of the highly-ionised atoms in stellar interiors is very great. *Radiation Pressure*, the momentum of radiant energy, and proportional to the 4th power of the absolute temperature, is very great inside a star, and largely contributes to the support of the super-incumbent matter. It also seems responsible for comets' tails; as the weight of spheres diminishes as the cube, and their projected areas as the square, of the diameter, for exceedingly small particles in the comet, when near enough to the Sun, a point is reached at which radiation pressure exceeds the gravitational pull, and these particles will be repelled from the Sun.

Star Diameters.—The angular diameters of the stars are far below the limit of direct angular measurement, but, in 1921, interferometer measures showed that *Betelgeuse*, *Antares*, *Arcturus*, and later, *Mira*, have angular diameters of ·047″, ·041″, ·022″, and ·056″, corresponding to 217-, 400-, 210-, and 125 million miles respectively, less or more, according to the parallax adopted. (The mileage for any parallax may be found by the simple rule given below). *Betelgeuse*, however, apparently pulsates, varying from 0″·034 to 0″·047. Stellar diameters can also be calculated on the basis of surface brightness and visual magnitude (see 'Luminosity').

The diameters of White Dwarfs are of planetary size, *Sirius B* being rather smaller than Neptune; and A.C. + 70° 8247, roughly half the size of the Earth.

Diameter in Miles.—Multiply the angular diameter in seconds of arc by 93,000,000, and divide answer by the annual parallax.

„ **Kilometres.**— „ „ „ „ „ 150,000,000, „ „ „ „ „

Stellar Rotation.—In some spectra all the lines are equally wide, mostly faint, and fairly sharp-edged; the metallic lines being wide, the Stark effect cannot be responsible. The wide lines are interpreted as being due to the star's rapid rotation, the widening being the effect of the lines produced by each limb, which are displaced in opposite directions. The most rapid rotation yet found is that of *Altair*, 260 km./sec. (160 m./sec.), which rotates in about 7 hrs., although its diameter is about 1½ times that of the Sun. Smallest velocity detectable, about 30 km./sec.

Star Velocities are best known from the radial velocities, found by the spectroscope with considerable accuracy: it gives the minimum-possible value for the 'space' or real velocity, which, in general, is greater, but is known less accurately, its other factors of parallax, proper motion, and solar motion, being more or less uncertain. The space-velocities cannot, however, differ greatly from the radial ones, unless the cross velocity is relatively great. As cross velocities, on the average, apparently do not differ greatly from the radial ones, the average space-velocity may therefore be taken to be of the order of 1½ times the radial velocity, *i.e.* the approximate resultant of two equal velocities at right angles. Velocities are expressed in kilometres or miles per second (contracted, 'km./sec.', m./sec.).

The majority of star velocities are under 30 kilometres (19 miles) per second, those of 50 km. (31 miles) are not common; but there are notable exceptions, RZ Cephei having the enormous velocity of 1100 km. (680 miles) per second. This is far surpassed by the spiral nebulæ, which seemingly speed through space with velocities approximately proportional to their distance (about 500-550 km./secs. or 310-340 m./secs. per megaparsec), up to 200 million light-years. or more, for which the corresponding speed is some 2650 million kilometres (1650 million miles) per day (Table p. xi).

On the average, velocities tend to increase with advancing Type, as shown by the Table of approximate average radial velocities *(Campbell, &c.)* below: the velocity also increases as the absolute magnitude increases. The velocities of the few R stars known, fall into three groups; under 10 km./sec., about 40 km./sec., and high velocity 250-380 km./sec.

Radial Velocity :— *Type*	O	B	A	F	G	K	M	Me	N	R	Se	P
Km. per sec. ...	25½ km.	6½ km.	11 km.	14½ km.	15 km.	16¾ km.	17 km.	35 km.	18 km.	21 km.	24 km.	30 km.
Miles per sec. ...	16 miles	4 m.	7 m.	9 m.	9 m.	11 m.	11m.	22 m.	11 m.	13 m.	15 m.	18½ m.
Mean abs. mag. (Dwarfs)	−4·5	−2·4	+0·6	+2·6	+4·4	+6·2	+9·8	...	...	...	...	(gaseous
„ „ (Giants)				−0·6	+0·3	+0·6	0·0	−0·5	(−1·5)	(−1·5)	(+0·4)	nebulæ)

* Approximately, within 32°.

Stellar Equipartition of Energy.—While there are considerable differences in the velocities of individual stars in each Type, stars of low velocity, *on the average*, have large masses, and those of high velocity small masses, The kinetic energy of each star—the velocity squared multiplied by half the mass—is also, on the average, approximately a constant quantity. This has been shown to result from the inter-action of the stars on one another over enormous periods. The B stars, however, do not conform to the rule.

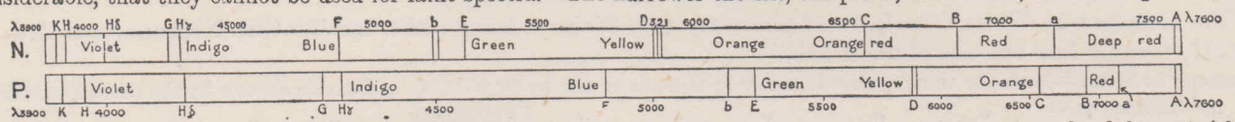
Light-Absorption in Space seems to be almost negligible, as the distances derived from the brightness and diameter of the remotest spiral nebulæ are fairly accordant. Within our System, however, especially near the Galactic plane, evidence favours a slight absorption, which *reddens* the stars—*i.e.*, lessens their maximum intensity, displacing it nearer the red than the normal for their Type—making absolute magnitudes less than they should be, and distances derived from them too great. For 0·7 mag. absorption per 1000 parsecs, at 500 parsecs the real distance would be 14% less than the apparent; at 1000 parsecs, 24% less; at 5000 parsecs, 56% less; but later evidence favours a smaller absorption, 0·40 mag. per 1000 parsecs being the most probable for uniform interstellar absorption in the Galactic system.

Colour Excess is the greater redness of a star (or external galaxy) over a normal star of the same spectral Type; it implies some special factor, such as giant and dwarf difference (p. 20), or space reddening.

IV. SPECTROSCOPY.

Spectroscopy has now become of such far-reaching importance in astronomical research that some knowledge of its salient facts and terminology has become a *sine qua non* for understanding the differences between the various Types of stars, and the references in current astronomical literature. A similar knowledge of the atomic changes giving rise to the various spectra is also useful: the following brief outline may help those unfamiliar with the subject

Light is supposed to be due to undulations or waves in a (hypothetical) light-transmitting medium known as the ether; these light-waves are of infinite variety in their crest-to-crest or 'wave-length' distances, some being exceedingly short, others comparatively long, but the eye only perceives those within narrow limits. The shortest wave-lengths visible produce the sensation of violet in the eye; those about twice as long, the sensation of red; those of intermediate wave-length give the sensation of blue, green, yellow, orange, &c. The light from an object is analysed by passing it through a slit in the spectroscope 1/500th to 1/1000th inch wide, then either (*a*) through a prism or prisms; or (*b*) letting it fall obliquely on a finely-ruled 'grating': in both cases the narrow beam of light is spread out, or 'dispersed,' either into a long coloured band, or, for some kinds of light, into a series of separate hair-like coloured lines. (*a*) forms what is known as a *prismatic* spectrum, in which the wave-lengths at the red end are much less spread out than those at the violet end; (*b*), a *normal* or *diffraction* spectrum, in which the dispersion is uniform throughout, and spreads out the red end to better advantage than a prism does; the loss of light in gratings, however, is so considerable, that they cannot be used for faint spectra. The narrower the slit, the purer, but fainter, the band spectrum.



N. 'Normal' or 'Diffraction' spectrum; dispersion uniform. **P.** 'Prismatic' spectrum, same length: small dispersion red end, large at violet end

*A λ7594, *Telluric*	C λ6563, *Hydrogen, Hα*	D_2 λ5890, *Sodium*	E λ5270, *Iron & Ca.*	F λ4861, *Hydrogen, Hβ*	H λ3968, *Calcium*
B 6867, „	D_1 5896, *Sodium.*	D_3 5876, *Helium*	b_1 5184, *Magnesi'm*	G 4308, *Iron (& Calc'm)*	K 3934, „

Angstrom Units.—The crest-to-crest distances, though very minute, can be measured with great accuracy, and are expressed in *Angstrom Units* (contracted, A.U., or angstroms)—each 1/ten-millionth (10^7) of a millimetre, or a 'tenth-metre'—symbolised by the Greek letter λ (denoting Ang. wave-length), followed by the number of ten-millionths from crest to crest.†

The International Primary Standard wave-length to which other lines are referred, is λ6438·4696, the wave-length of a red line emitted by gaseous cadmium, and units on this basis are designated 'I.A.' (International angstrom), as the original A.U. was slightly over-valued. There are 'Secondary' and 'Tertiary' standards, using the lines of other elements. (See *Tr. I.A.U.* 1922-28).

The Greek letter μ is sometimes used instead of λ, especially for the longer wave-lengths, indicating that the figures are in thousandths of a millimetre (microns) instead of ten-millionths; μμ, or millionths of a millimetre, are also sometimes used. Thus μ 0·64384696 = μμ 643 84696 = λ6438·4696. λλ is used as the plural of λ. (λ = μ × 10,000; μ = λ ÷ 10,000).

The Visible Spectrum ranges from about λ3900 in the extreme violet, to λ7600 in the extreme red, but it has no definite limits, as eyes vary in sensitivity. Unseen, beyond the violet, is the *ultra-violet* spectrum, of ever-shortening wave-lengths, recorded by ordinary photographic plates up to about λ2000, and by special apparatus to λ150. Beyond the red, also unseen, is the *infra-red*, of ever-lengthening wave-lengths, sometimes called the 'heat spectrum'; it is traceable to λ12,000 by special photographic plates, thereafter by other means, to the limit of the solar spectrum, about λ50,000—but there are wave-lengths far longer and shorter than these limits. Oxygen in our atmosphere, and an ozone layer high up, absorbs all radiation from outside shorter than λ2900, except Cosmic; in the infra-red, less than 1% of the solar radiation is of greater wave-length than λ40,000 (4μ).

Conventional Divisions of Wave-length (boundaries indefinite, each kind gradually merges into the next: λ = angstroms).

γ-rays (Invisible)		X-rays (Invisible)		Ultra-violet	Violet light	Red light	Infra-red	Hertzian
Hard, to:	Soft, to:	Hard, to:	Soft, to:	(Invisible), from:	(Visible) from:	(Visible) to:	(Invisible)	(Radio)
·000,000,000,5 cm.	0·000,000,04	0·000,000,001 cm.	0·000,000,25	0·000,001,4 cm.	0·000,039 cm.	0·000,076 cm.	from λ7600	0·1 metres
λ0·005	λ4·0	λ0·1	λ25	λ140	λ3900, or	λ7600, or	to ·003 cm.	to 25,000 „
					0·39μ	0·76μ	to 30μ	

Cosmic (invisible), 0·000,000,000,004 cm. (λ0·0004, see p. 21).

The Effective Wave-length of a radiating body may be stated generally as the wave-length at its average intensity, *for defined conditions*—visually, photographically, &c.—the wave-length at which the amount of such radiation is equal on each side.

* Fraunhofer's letters run from red to violet; violet to red is now preferred—wave-length order. † *Frequency* is also used—the number of undulations per second.

Emission and Absorption Spectra.—An incandescent solid, liquid, or gas under *high* pressure, gives what is called a *continuous spectrum*, when the light it emits is passed through the prisms of the spectroscope. In other words, it emits light of all wave-lengths between the deepest red and the deepest violet. Under ordinary pressures, however, each elementary substance in the gaseous state emits, when excited, only certain definite wave-lengths peculiar to itself, the rest of the spectrum being missing; in the spectroscope these appear, when a narrow slit is used, as a series of isolated hair-like bright coloured lines, forming an 'emission' or bright-line spectrum, and the appearance of these particular lines always indicates the presence of that element.

On the other hand, each element in the gaseous state cuts out or absorbs, from continuous-spectrum light traversing it, the *identical wave-lengths that it emits when excited*, so that in the spectroscope, the light seen after the absorption is no longer continuous, but broken up by a series of hair-like dark lines (the image of the slit) where the absorbed wave-lengths are missing. These dark lines occupy the same positions as the bright lines of the emission spectrum, and are called *absorption lines*; they not only indicate the presence of the element, but also tell that it is at a lower temperature than the light-source behind it, as absorption only takes place if the emission of the absorbing substance is less than that of the emitting substance behind. Absorption lines are also found in the ultra-violet and infra-red. Many elements are represented by hundreds of lines—sometimes thousands, as iron.

Fraunhofer Lines.—The dark lines of the solar spectrum are called after Fraunhofer, who re-discovered them in 1814, and lettered the most prominent ones as in the Table above, which also gives the corresponding element and wave-length: (L), (M), &c., in the ultra-violet, were added later, and the original (H^1) and (H^2) re-lettered (H) and (K). But as the same letters are also used for star Types, and as chemical symbols for elements, to prevent confusion the I.A.U. recommended as follows, in 1922:—

Letters denoting Fraunhofer lines in astronomical works: should be printed in ordinary Roman capitals, in parentheses.
" " **Chemical Symbols** " " " " " *italic* capitals.

The (H) Fraunhofer line (calcium), must not be confused with $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, &c., lines—so lettered by Vogel—which denote the 'Balmer' series of hydrogen lines belonging to the normal hydrogen spectrum (only four appear in the ordinary solar spectrum); other 'series' of hydrogen lines appear under different conditions. $H\gamma$ is λ 4340; $H\delta$, λ 4102. b_2 (λ 5173) is magnesium.

Telluric or atmospheric lines in the spectrum as (A), (B), oxygen; and (a) water vapour (λ 7185), result from absorption by the oxygen and water vapour in our atmosphere, and have no place, or only a very faint place, in spectra before they reach the Earth.

Bands, groups of very close lines—one side sharp, the 'head'—in low-temperature spectra indicate a *molecular spectrum*, i.e., one produced by molecules, atoms of two elements chemically combined; the ordinary spectrum is that of the normal or neutral atom (see below). A *fluted* spectrum is one that has recurring groups of lines or narrow bands, giving it a fluted appearance.

Flame, Arc, and Spark Spectra.—The lines produced by each element are not the same under all circumstances, being changed or modified under different conditions of temperature, pressure, &c., especially the former. The *Flame*, *Furnace*, or low-temperature spectrum given in a Bunsen burner (some 2000° C.) has comparatively few lines, and differs in some respects from that of the *Arc* spectrum obtained in the electric arc at a temperature of some 3600° C., in which new lines may appear. The *Spark* spectrum, again, produced by high tension discharges, has different characteristics from that of the arc one, some 'low-temperature' lines, that have been fading as the temperature rose, disappearing altogether, while other lines are '*enhanced*' (p. 25), that is, have grown more intense. Spectra can be studied up to temperatures of some 20,000° C., by electrically-exploded wires.

Doppler Effect, or the displacement of the lines as the result of motion of the light-source in the line of sight, is of great importance, as it enables radial velocities and rotation periods to be found, and spectroscopic binaries to be discovered. If a source of light is approaching the observer, any lines seen in its spectrum will not be in their normal positions, but some distance nearer the violet end of the spectrum, or if the light-source is receding, nearer the red end of the spectrum. As the displacement is proportional to the velocity, the radial velocity can be calculated by identifying a series of lines and measuring the amount of shift.

In the case of a binary star, each star produces its own set of lines; when both stars are in the line of sight, the two sets are super-imposed and appear as a single set, there being no orbital radial motion towards us, as their motions are at right angles to the line of sight. But when the stars open out again, one star is moving towards, and the other away from us, so that the two sets of lines separate in opposite directions, and reveal the duplicity, and the respective orbital radial speeds; the same principle applies to the opposite limbs of the Sun, of a rotating planet, or of a star (p. 21), one of which is moving towards, the other from us.

Interstellar Lines.—Sometimes in Novæ, and in O- and B-type binaries, which are very distant, a third set of practically stationary lines of calcium and sodium appears. These lines are now known to result from the presence of interstellar matter, uniformly distributed, in general, through our System, and which rotates practically with the Galaxy: in stars nearer than say 1000 parsecs, it does not reveal its presence, because their light does not traverse a sufficient length of the absorbing medium to produce a perceptible effect. The more distant the star, the stronger the lines, which property can be used to find the star's distance (p. 14).

Zeeman Effect.—If a magnetic field is present, lines normally single may split up into two or more lines—from which the polarity of sunspots, and the position of the Sun's magnetic axis are found.

Stark Effect.—The splitting up of lines by an electric field; those of helium and hydrogen are greatly affected, those of the metals but little; thus it can be distinguished from the Zeeman effect. The hazier the helium and hydrogen lines, the stronger is the electric field, and the more prominent the forbidden lines; also the denser the stellar atmosphere must be, to give the electric field required to allow the forbidden lines to be produced in quantity. (See also Stellar Rotation, p. 21).

The Atom and its Properties.—The varied stellar spectra, and most of the above 'effects', are due to internal changes in the atoms of the elements in the stellar atmospheres, under different temperature and pressure conditions; the following main facts underlie the various phenomena, on the Rutherford-Bohr theory, which explains them well, though not completely.

The atoms of an element are the smallest particles distinguishable by chemical means; those of each element differ in weight and properties, but all are built up of the same fundamentals—*protons*, *electrons*, and energy. Each proton (*i.e.* hydrogen nucleus, see p. 24) has a constant positive charge of electricity; and each electron (mass only 1/1847th that of the nucleus), an equal negative charge. In the normal atom, these charges balance, and there being no electric field, in this condition it is called a *neutral atom*.

The Structure of the Atom.—Atoms are pictured as miniature sun-and-planet systems, the atom of each element being supposed to consist of a nucleus (extremely small, even compared with the tiny atom, and itself composed of protons and neutrons, see below), positively charged, and surrounded by one or more 'shells' (orbits) of electrons: each electron carries a single negative electric charge, each orbit only one electron.

In its normal (non-ionised) state, an atom is not charged with electricity, hence the number of unit positive charges (protons) in its nucleus is equal to the number of electrons which surround it; this number is called the *atomic number* (different from the *atomic weight* or mass of the element), and determines its chemical properties. Elements range in atomic number from 1 (hydrogen, the simplest, with one electron) to 92 (uranium, with 92 electrons revolving round the nucleus).

The K-ring, &c.—The electron-orbits are spaced in groups, each member of which has about the same energy and diameter, but may differ in eccentricity. These groups are known as *Rings*—usually, more appropriately, as *shells*, because the members of each group presumably move in different planes, their diameters being about the same.

The group nearest the nucleus consists of two orbits of equal energy known as the *K-ring*, which has the lowest energy of all the rings; next comes the *L-ring*, with eight orbits; then the *M-ring*, with 18 orbits, and so on; the outer ring of an element's electrons may contain only one electron. The chemical and spectroscopic quantities of an element are largely determined by the number of electrons in its outermost layer; these are also the most easily 'excited' or 'ionised' (knocked off, see below).

Collisions.—The atoms of a gas, under the action of the heat which it contains, rush about at very high speeds—to which gas pressure is due—and are incessantly colliding; the higher the absolute temperature (p. 21), the greater their speed, and the more violent the collisions. In a rarefied gas—*i.e.*, one at a very low pressure—the journey without any collision, or *free path*, of the atom is long, the distance between the atoms being relatively great; collisions are therefore less frequent than in a dense gas.

Molecules.—At ordinary terrestrial temperatures, gases do not exist as single atoms but as *molecules*, composed of a pair (or more) of atoms in combination, either of the same or a different element; when the temperature rises sufficiently, however, molecules are *dissociated*—*i.e.*, revolved into single atoms—few exist even at the lowest stellar temperatures. The speed of the molecules composing a gas is proportional to the square roots of:—*(a)* their molecular weight, inversely, *(b)* the absolute temperature, directly; the lighter the gas, and the higher the temperature, the greater the velocity of the molecules—each gas having its own velocity for a given temperature. Left to themselves, the molecules would dissipate into space, but on a sufficiently massive body, the gravitational force retains them with a force depending on the body's mass and radius—an important factor in planetary atmospheres.

The Velocity of Escape is the velocity at which a planet's mass ceases to be able to retain a gas (p. 35). Hydrogen, the lightest element, is lost first, then helium, water vapour, oxygen, nitrogen; carbonic acid last, but at velocities no greater than a quarter of the velocity of escape, gases dissipate into space rather rapidly. For the velocities of escape, see p. viii.

Quanta.—The energy component of an ('excited,' see below) atom is stored up in (popularly) 'energy-atoms,' which cannot be sub-divided. Each of these is known as a *Quantum* (plural, quanta), and represents energy equivalent to that of radiation of some particular wave-length, quanta of long wave-length having small, those of short wave-length great, energy. (*Short* and *long* wave-length, as general terms, denote those at and beyond the blue and red ends of the spectrum, respectively).

There are quanta corresponding to all wave-lengths, each element having its own particular quanta of energy, corresponding to those wave-lengths of radiation which its atoms emit or absorb under different conditions: only quanta with nearly these wave-lengths can effect 'transitions' in that kind of atom, but those of shorter wave-length may 'ionise' the atom—*i.e.*, knock off one or more of its electrons (see below). The amount of short wave-length energy in a gas depends on its absolute temperature; thus, at high temperatures, short wave-length quanta are more plentiful than long ones. To sum up; in a stellar atmophere:—

Temperature is an index of (*a*) the number of atomic collisions per second, for a given pressure; (*b*) the speed of the atoms; (*c*) the violence of the collisions; (*d*) the proportion of short wave-length energy.

Pressure only affects the frequency of the collisions, by increasing or decreasing the distance between the atoms.

Transitions.—When all the electrons of a neutral atom are revolving in the orbits nearest the nucleus, the atom is said to be in its *lowest energy* or *ground* (normal) state. But (*a*) by a sufficiently violent collision with an electron or another atom, or (*b*) by encounter with, and absorption of, a quantum of energy of wave-length the same as one of its own fundamental quanta, an atom may undergo *transition*, being 'raised' or lifted to a 'higher level'—*i.e.*, of energy, and from that, it may be, to still higher and higher levels, the electron being forced out into an orbit of larger diameter, in accordance with certain laws. *Forbidden transitions* are those forbidden by these laws, though they may occur in certain unusual sequences or steps.

Excitation.—At every transition of an electron to a larger orbit, a quantum of definite wave-length is absorbed by the atom, which is then said to be *excited*: it thus becomes a greater and greater reservoir of energy as the excitation increases; whatever the amount of excitation, however, it still remains a 'neutral' atom.

If left undisturbed, an excited atom 'falls' back to its lowest energy state in a hundred-millionth of a second, emitting in the process as many quanta of the same wave-lengths as it has absorbed; the process may be accomplished in stages. Certain transitions, however, are *metastable*—that is, if left to themselves, excited atoms in that state may continue in it for hundreds of thousands of times longer than ordinary excited atoms are able to do, sometimes even for seconds.

Ionisation.—An electron of a neutral atom may not only be raised to a larger orbit, but may also be completely knocked off, and left to travel on its own account; the atom is then *ionised*, and is no longer neutral, but positively charged, the negative electron being lost. Ionisation may be caused (*a*) by a sufficiently violent collision; (*b*) by encounter with a quantum of short wave-length, with more than sufficient energy to lift an electron to the outermost level. Ionised atoms may also be excited.

Atoms may be singly, doubly, trebly, &c., ionised. The neutral atom is indicated by the chemical symbol of the element with the Roman numeral I affixed, as *O* I*, neutral oxygen; for singly and doubly ionised, II, III, are added, and so on, as *O* II, *O* III.

An older system affixed a small + for single ionisation, ++ for double, and so on, instead of Roman numerals, as O^+, O^{++}; still further back, the atoms causing enhanced lines were known as protocalcium, protomagnesium, &c.

Atoms vary in the amount of energy required to excite and ionise them, and the amount of energy denoted by 1 (electron-) volt† is taken as the unit of measurement. The number of (electron-) volts required to excite, or to ionise, the atom of each element, is called its *Excitation* and *Ionisation Potentials*, the latter, of course, being greater than the former (see Table, p. xi).

* Large capitals are also used, but the small capitals are much clearer. † Somewhat different meaning from the ordinary volt.

The Mass of the Atom, or *atomic weight*, consists almost entirely of the mass of the nucleus, and ranges from that of the hydrogen atom (approx. unity, 1·007), to the 238 of the uranium atom (the standard is oxygen, 16). Generally, but not always. the weight of the atom increases as the atomic number. Several elements may exist having identical atomic numbers, but differing in mass (atomic weight). Such elements, which are chemically identical, are called *isotopes.* Thus, in ordinary common salt, the chlorine (atomic *number*, 17) consists of a mixture of two isotopes of masses (or atomic *weights*) 35 and 37, while hydrogen as normally found contains traces of an isotope of mass 2 (deuterium or heavy hydrogen, symbol *D*).

Rays.—The heaviest elements and their isotopes, and some of the isotopes of the lighter elements, are *radio-active*, that is to say, their nuclei break up spontaneously, into other nuclei and particles, some of which (electrons or β rays, helium nuclei or α rays) may be ejected at very high speeds—when fastest, and most penetrating, being known as *hard* rays; when slower, *soft* rays. They also give out electro-magnetic radiations, called γ rays, which resemble X-rays, but are of harder (*i.e.*, shorter) wave-length.

When an α ray (a rapidly-moving helium nucleus) strikes another nucleus it may cause it to break up into lighter nuclei. In these changes, uncharged nuclei of mass 1 (*neutrons*), and particles of extremely small mass (*neutrinos*), are sometimes emitted. They can be detected only when moving at high speeds, and being small and uncharged have great penetrating power.

Cosmic radiation, arriving from unknown sources in space, may consist either of very high speed 'cathode' or β rays (moving electrons) or of electro-magnetic radiation of even shorter wave-length than γ rays. This radiation, striking atoms, may give rise to rapidly-moving *positrons*, similar to electrons but carrying a positive instead of a negative charge of electricity.

The following Table shows the relationship of some of the lighter charged particles and atoms (the mass rises with the speed, increasing enormously as the speed approaches that of light). The third column gives an idea of the bulk of the particle—for the more the atom is ionised (p. 24), the less is its bulk, especially when completely ionised.

Name	Total charge	Approx. Mass	No. of electrons
Neutrino ...	0	0	0
Positron ...	+1	0	0
Electron (β Ray)	−1	0	0
Neutron ...	0	1	0

Name	Total charge	Approx. Mass	No. of electrons
Proton (Ionised *H*)	+1	1	0
Hydrogen atom (*H*)	0	1	1
Deuteron (Ionised *D*)	+1	2	0
Deuterium atom (*D*)	0	2	1

Name	Charge	Mass	electrons
α Particle (dbly ionised *He*)	+2	4	0
Singly ionised (*He*) ...	+1	4	1
Helium atom (*He*) ...	0	4	2
... ...	...	...	...
... ...	...	...	...

Sets of Lines.—Each state of the atom gives rise to a different set of lines in the spectrum, the neutral atom causing one set, excited atoms other sets, and variously-ionised atoms others still; pressure also affects the appearance of the lines. And in stellar atmospheres of similar composition, for a given temperature and pressure there is always definite proportion of atoms in each state.

The strength of a line is proportional to the number of atoms producing it; strong lines indicate plentiful atoms in that condition, faint lines relative scarcity. Strong lines usually have *Wings—i.e.*, shading on both sides of the *Core*, or line itself.

Contours of Lines.—The degree of blackness at any part of the shading of a winged line, with reference to the background, is known as the *Contour* of the line at that point—so called because the energy-curve obtained by plotting the various intensities according to wave-length and blackness, is analogous to the gradient-curve obtained from the contour lines on a map.

Enhanced Lines, in a spectrum, are due to the normal atoms becoming ionised, losing one or more electrons as the combined result of higher temperature and altered pressure (*Saha Effect*); each element has its own ionisation conditions, thus the presence (or non-presence) of certain lines in stellar spectra affords a clue to the physical conditions in the stars' atmospheres.

Forbidden Lines are produced by possible, but very unlikely, 'transitions' (see page 24) in the atom, which cannot directly return to the ground state, but only through other transitions; an electric field, however, cancels the unlikeliness, and with a field of sufficient strength the lines become visible. The appearance of forbidden lines in a star's atmosphere indicates that it is dense, the electric field being due to the close ionised atoms and free electrons, but in a nebula they become possible as the result of the extreme tenuity—some 1/1000-millionth of an atmosphere—and 'weak' (*i.e.*, not too strong) radiation of very high energy, such as the short wave-length radiation from O and B stars.

Ultimate Lines.—Those fundamental lines of an element that alone persist under great rarefaction. When about the region of the spectrum which cannot ordinarily be observed, those that can be observed are known as *Raies ultimes.*

Interpretation of Spectra.—At very low pressures, as in the Giant stars (p. 20), for a given temperature the wave-length energy available is the same, and the violence of collision the same, as in dense stars; excited and ionised atoms are also present in both. But when an atom is ionised, the distances apart in a rarefied gas being great, there is less chance of its recapturing an electron, so that the proportion of ionised atoms is greater, and that of the neutral atoms less; the Giant star will, therefore, have stronger ionised-atom lines and weaker neutral-atom lines, than those in the spectrum of a dense star of about the same temperature; its lines will also be narrow and sharp—the '*c*' characteristic (p. 19). In dense stars, on the other hand, distances apart being small, ionised atoms soon recapture an electron, thus the neutral-atom lines are strong, the ionised-atom lines faint.

At the low temperature of the furnace spectrum, the lines of the excited atoms are faint (being chiefly those of the more-easily excited elements), while those of the normal (lowest energy-state) atoms are strong, the proportion of the latter atoms being the greatest. With rising temperature, owing to the more violent collisions and the greater supply of short wave-length quanta, the excited-atom lines grow stronger, owing to the ever-increasing quantity of atoms in that condition, and at last, at the arc spectrum temperature, ionised lines of the easily-ionised elements also begin to appear—some even appear in the furnace spectrum.

At a later stage, the neutral-atom lines disappear, those of the easily-ionised atoms first, the more refractory later. Thus the spark (lower-temperature) spectrum has faint neutral lines and strong enhanced or ionised lines, because ionised atoms now preponderate; faint lines of the atoms most easily doubly-ionised will also begin to appear in the lower-temperature spark spectrum.

At still higher temperatures, the ionised lines also disappear, being gradually replaced by the lines of doubly and trebly ionised atoms, and finally, at the highest obtainable spark temperature, and the still higher temperature of the O stars, hardly any lines are left in the visible spectrum except those of hydrogen and ionised helium—the latter of which has a very high ionisation potential. Lines of other elements, however, exist, but mostly in 'inaccessible' (unobservable) positions in the ultra-violet.

Planetary and Gaseous Nebulæ, on the other hand, in which the distances between the atoms is enormous, do not shine by their own light, but by absorption and re-emission of short wave-length radiation of O and B stars within them; they contain atoms which are doubly and singly ionised.

V. THE SUN, MOON, AND PLANETS.

The Sun, as an object for small telescopes, is of little interest unless sunspots are visible: special precautions are required in observing it so as not to injure the eyesight (see p. 40).

The disc of the Sun visible on ordinary occasions, known as the *photosphere*, presents a granular or 'rice-grain' appearance in large telescopes. Even in a small instrument of 2 or 3 inches aperture, the surface will show a mottled appearance, when the air is steady and definition good; but this mottling is of a coarser texture than that delicate granular appearance seen under higher powers with large instruments. *Faculæ*, *i.e.*, irregular, more or less streaky patches, somewhat brighter than the average surface, may generally be seen. They are elevations above the general level of the photosphere, and exist on every part of the disc, but are most numerous in the neighbourhood of sunspots. They are best seen near the limb or edge of the disc, since the photosphere in this region is perceptibly darker than at the centre of the disc, having only some 37 per cent of the brilliancy, according to Pickering. This is due to the absorption by the Sun's atmosphere of the light coming from within, which has to traverse a much greater depth of atmosphere at the limb, before reaching the Earth, than that coming from the centre: it therefore appears darker to us, contrasted with the faculæ, which have not lost so much light owing to their greater elevation. The darkening is specially noticeable in solar photographs.

The Sun's Rotation may be traced by the daily motion of the spots across the disc from east to west, the 'synodic' apparent rotation period, as seen from the Earth, averaging 27¼ days: spots may thus be visible for about a fortnight at a time. The sidereal or true rotation period is about 25 days near the Equator, and 27 days at 35°; the synodic rotation period, at these latitudes, varies in about the same proportion. The mean sidereal rotation period at present used in the *N.A.* and *A.E.* is 25·38 days (27·2753d. synodic), but a 25·2-day sidereal period, 27·1 synodic, is perhaps nearer the true value, being that favoured in the recurrence of sunspots, faculæ, flocculi, prominences, and magnetic storms. The Sun's axis of rotation is inclined 7¼° from the vertical to the Ecliptic plane (see p. 40).

Carrington's Series of Rotations (25·38 day), used for statistics, has as zero meridian the Sun's prime meridian that passed through the ascending node at 0 h., G.C.T., Jan. 1, 1854; **No. 1** began Nov. 9, 1853; **1101**, 1936, Jan. 2·74 (17 h. 46m).

Sunspots vary in size from small 'pores,' as the smallest are termed, to groups so large as to be visible to the naked eye, on occasion. A sunspot presents the appearance of a dark irregular spot, or *umbra*, surrounded by a less dark portion, or *penumbra*; the *umbra*, however, is only apparently dark by comparison with its surroundings, being actually brighter than the electric arc, though its darkest portion, the *nucleus*, has only about 1 per cent of the brightness of the average surface: very black, round spots, known as *nucleoli*, are often seen in the umbra. *Bridges* from the photosphere, often intensely bright, may frequently be seen gradually encroaching on and dividing up the penumbra and umbra; in large spots, these can easily be seen with a 3-inch telescope, or even less. The size of spots varies from about 500 miles to some 50,000 miles in diameter. Those over 15,000 miles are *Naked-eye Spots*, visible without a telescope, when the Sun's brightness is sufficiently reduced by cloud, mist, or dark glass. The diameter of the spot, including the penumbra, may usually be roughly reckoned as being three times the diameter of the umbra.

The umbra is usually some 2000 to 6000 miles lower than the general surface, which results in the *Wilson Effect*, the apparent displacement of the umbra as a spot approaches the limb. On rare occasions, when of unusual size and depth, a spot is visible as a small notch on the Sun's edge when just coming into or going out of view.

Sunspots are never seen at the Sun's poles, and rarely within 5° of the equator. They occur mainly in two zones between 10° and 30° of N. and S. solar latitude. Spots in 45°-50° are rare, and no spot has yet been recorded beyond 60°. Sunspots have magnetic fields, and the polarity, + or −, of the 'preceding' or foremost spots of a group is opposite in the N. and S. hemispheres—which hemispheres may differ very considerably in their spottedness.

The Sunspot Period.—The spottedness waxes and wanes, a maximum being reached about every 11·1 to 11·15 years, on the average, but there is no definite period, intervals between maxima having varied from 7½ to 16½ years; the apparent 11-year cycle, however, is really a half-cycle, for the spot-polarity changes after every minimum.

The rise to maximum is usually more rapid than the fall, taking about 4½ years; minimum spottedness is reached about 6½ years later, when no spot may be visible for weeks. Large spots may appear at any part of the cycle.

Spoerer's Law states that the two spot-zones simultaneously move slowly from high N. and S. latitudes towards the equator. Nearing minimum—the end of each half-cycle—the spot-zones are near the equator; the new half-cycle begins when spots of opposite polarity break out in high latitudes, some time before the actual minimum is reached, and two or three years elapse before old-zone spots finally disappear. The new spot-zones gradually decrease in latitude, till, at the end of eleven years, they, in their turn, arrive near the equator; high-latitude spots of opposite polarity then appear, heralding the beginning of the second half of the cycle.

The variation of latitude is shown in a striking manner by plotting the spots of a cycle according to date and latitude. From its shape, this is known as a *Butterfly Diagram*.

* Spots not on the centre are, of course, greatly foreshortened when near the limb.

Sunspots and Magnetic Storms.—The curves of sunspot activity, of terrestrial magnetic storms, and (on the whole) of auroræ, closely coincide, indicating some intimate connection not yet wholly explained. A large spot near the centre of the disc often coincides with a magnetic storm, but not always, and on the other hand the return of a certain area to the centre of the disc sometimes causes a magnetic storm, though no spot is visible.

Wolf's Sunspot Numbers give the relative 'sunspot activity' for any year, based on the number both of groups and of individual spots—the size of telescope used, and the observer, being taken into account. The numbers vary from 0 to about 150 at the highest maximum, and they have been calculated back to 1610 (See Memoirs R.A.S., vol.43). A sunspot number of 100 is equivalent to a sunspot area of about 1/500th of the visible disc.

Prominences or *protuberances* are jets or clouds of glowing red gas which rise all round the Sun's 'limb' or edge from the *chromosphere*, a bright scarlet, irregular ring of light, some 5″ to 15″ in depth at different times, seen only during total eclipses, or by means of a spectroscope attached to the telescope (see p.40). *The reversing layer* is a thin stratum of gas which is responsible for the dark lines in the solar spectrum, absorbing certain portions of the bright light from the layers beneath, and reversing them into dark lines. In solar eclipses, just before the Sun disappears, it shows the lines bright instead of dark—a phenomenon known as the *flash spectrum.*

Filaments are long dark prominences seen in projection on the Sun's disc. *Motion-forms* are apparent filaments over a sun-spot, but in reality only distortions of the hydrogen (C) line caused by high radial motion.

Flocculi, seen or photographed by the spectro-heliograph, in one particular wave-length of light (usually that of calcium, sometimes hydrogen), are small irregular clouds of either of these elements, which are seen all over the disc, and show the distribution of the element over it. There are both bright and dark flocculi: the latter may take the form of long dark wisps. The *Solar Reseau*, or *Reseau Photospherique*, is an as yet unexplained blurring or fuzziness of the solar granulation; it is not known whether it is of solar or terrestial origin. ('Reseau' also means the network of squares ruled on celestial photographs for measuring purposes).

The Corona, also seen only during total eclipses, is a mysterious, irregular, pearly ring of light surrounding the Sun. It is never quite the same, either in shape or extent, in successive eclipses, and appears to be partly gaseous, and partly meteoric, for it shines partly by reflected sunlight. It varies with the 11-year period of the Sun's activity, being more or less regularly distributed round the Sun at sun-spot maximum, while at sun-spot minimum there are large streamers, several degrees long, near the Sun's equator, with tufts or plumes of light near his poles. Its brightness varies, being at times uncomfortably bright, nearest the Sun, without a dark glass, especially when the Sun's and Moon's diameters are nearly the same, but on the average seems rather less bright than the Full Moon. The Corona spectrum has a characteristic green line (λ5304) due to oxygen, once ascribed to an unknown element 'coronium'.

Baily's Beads are sometimes seen for an instant before totality—a breaking-up of the thin disappearing crescent of the Sun into a series of bright moving points, like a string of shining beads.* Then, as totality begins, the prominences and corona appear until the Sun begins to emerge again; sometimes, however, they appear just before totality.

Shadow Bands or fringes, another eclipse phenomenon, are alternate light and dark bands, a few inches broad and 1 to 3 feet apart, that appear on white surfaces for an instant as totality begins: probably due to irregular refraction.

The Sun's Magnetic Poles are about 6° away (but perhaps this varies) from his rotation poles; they rotate in 31·29 days (31d. 7h.), and were on the Sun's central meridian on 25th June 1914.

The Sun's Temperature, that of a dwarf G0 star, is about 6000° K. (10,000° F.) near the surface. The *Solar Constant*, the amount of heat received by the Earth (on entering the atmosphere) from the vertical Sun, is 1·93 gram-calories per minute on each square centimetre; variations of one to five per cent seem to occur from day to day. The temperature of sunspots is about 4800°K.—1000° C. (1800° F.) less than that of the general surface.

Solar Motion.—The *Solar Apex*, or *Apex of the Sun's Way*, is the point on the star sphere towards which the Sun is travelling with a velocity believed to be about 19·5 kilometres (12·1 miles) per second. The position of the Apex is ascertained from study of proper motions, or radial velocities, but determinations differ, often by many degrees, different sets of stars giving varying results. In the main, however, there is agreement as to the general direction of the Apex being in Hercules or Lyra, about R.A., 18 hrs., Dec. 34° N. (or, as usually stated in degrees, R.A., 270°, Dec. 34° N.). The *Solar Antapex* is the point diametrically opposite on the star sphere, R.A. 6 hrs., Dec. 34° S.

Mean Daily Spotted Area of the Sun in millionths of the visible hemisphere (projected area, corrected for foreshortening).

Year.—	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
Area. ...	7	152	697	724	1537	1118	1052	618	420	252	55	276	830	1262	1058	1390	1242	516	275	163	88
Mean Lat.	*23¼°*	*21¾°*	*18¾°*	*15¾°*	*14¾°*	*12¾°*	*10¾°*	*10½°*	*8°*	*8°*	*15¼°*	*22¾°*	*20¼°*	*18¾°*	*15°*	*13½°*	*10½°*	*9¾°*	*8¼°*	*4°*	*10¼°*

Sunspot Maxima and Minima (approx.; +, −, polarity of N. 'preceding' spots.)

Minimum	1901·7−	1913·6+	1923·6−	1933·8+	1944−	...	1934	1935	1936	1937	1938	1939	1940
Maximum	1905·6−	1917·6+	1928·5−	1937·4+	...	...	119	624	1141	2074	2019	...	...
							23¾°	*23¼°*	*20¼°*	*17°*	*14¾°*	...	...

* Probably due to irregularities on the Moon's limb.

THE MOON

General Notes.—The Moon is the most interesting of all the heavenly bodies for a small telescope. In an opera-glass the dark portions visible to the naked eye are seen to be the smoother portions of the Moon's surface; the remainder of the surface is a mass of craters of every size, from some of which brilliant white streaks radiate for a great distance. The most striking views are obtainable when it is about its first or last quarter, when the lunar mountains near the *terminator* (or boundary between the bright and dark portions), cast long dark shadows which give a fine effect of contrast with the bright sun-lit parts. At the time of full Moon this contrast is lost, though the systems of *rays* or bright streaks are then most in evidence, and an interesting field of study is the total, or nearly total, disappearance of prominent objects (*e.g.*, Maginus) for 2 or 3 days before and after 'Full,' while others (notably the craters, properly so called, see p. 30) can still be located by reason of their being brighter than their surroundings. This disappearance is very noticeable in formations traversed by the rays or streaks, as in the S. W. portion of the Moon. A low power should be used at first, for a general view of the disc. (See note on 'Observing the Moon,' p. 40).

The Moon always presents the same side to the Earth, so that one side of the Moon is never seen at all. Owing, however, to what is termed the Moon's *libration*, or apparent swaying, due to the inclination of its axis to its orbit, and to other causes, we sometimes see a little more on one side or another, so that altogether about six-tenths of the surface is visible at one time or another. A full description of the Moon is quite beyond the scope of the present work, but the following paragraphs, together with the map, and further notes, p. 30, indicate the principal features. Consult Elger's and Neison's detailed accounts and maps, also Goodacre's; Nasmyth's, and *Unser Mond* (Fauth). Proctor's volume deals particularly with her orbital and other peculiarities. See also Pickering's Photographic Atlas.

Lunar *plains*, the darker and smoother portions of the surface, were supposed by the early telescopists to be *seas*—which they much resemble under very low powers—and were named accordingly. More perfect instruments, however, revealed that the supposed seas were simply vast plains, by no means level, or smooth, possibly once the bottom of lunar oceans.

Lunar *mountain ranges* and peaks are much higher in proportion to the moon's diameter than terrestrial ranges are to the earth's diameter, some of them attaining a height of about five miles. The most conspicuous range is *The Apennines*, in the northern hemisphere of the moon, which rises like a wall from the *Mare Imbrium*. It is about 600 miles long, and its highest peaks attain a height of $3\frac{1}{2}$ miles—the heights being found by measurements of their long sharp shadows, nearly 100 miles long.

Lunar *craters*, which are such a prominent feature in lunar landscapes, are of all sizes from a hundred and fifty miles in diameter downwards. Craters often have one or more conical peaks within the crater walls, of which *Tycho* and *Gassendi* are fine examples; the largest with a fairly level bottom, and often no central peak, and with lower bounding walls than the craters proper, are called *walled plains*, of which *Plato* is the best example. The interiors of the craters are usually lower than the surface outside, but sometimes the reverse is the case. Frequently an old crater will be seen that has been broken into by a later one.

Lunar *rills* are deep, winding, narrow valleys, resembling the bed of a dried up stream. Lunar *clefts* appear like cracks on the smoother portions of the surface. It is difficult to realise that these hairlike markings are sometimes fifty or a hundred miles long and up to $2\frac{1}{2}$ miles in width. The greater number of clefts are to be seen only in pretty powerful telescopes. *Faults* are closed cracks in the moon's surface, and are numerous. They are visible owing to the surface on one side of them being higher than that on the other.

Lunar *rays* are the bright streaks which radiate from some of the principal craters. Unlike other lunar features, they are best seen about the time of full moon. The finest system of rays radiates from the great crater *Tycho*, in the southern lunar hemisphere. The strangest feature of these rays is that they are everywhere on the same level as the rest of the surface, and traverse unbroken both crater walls, valleys, and seas. No fully satisfactory explanation of their nature has yet been given.

Position Angle of the Moon's Axis.—This sways some 25° on each side of the hour-circle every month, the extremes being when her R.A. is about 0 hrs. and 12 hrs., *i.e.*, when crossing the celestial equator: it is about zero when her R.A. is 6 hrs. and 18 hrs. The amount is given in the 'Moon's Physical Ephemeris' in the *Nautical Almanac*.

Objects near the Limb. Those near the N. lunar pole are best situated for observation when the Moon has its greatest south latitude (about 5°), and *vice versa* for the S. pole; those near the west limb, when the Moon's actual longitude is E. of (*i.e.*, *greater* than), and those near the east limb when it is W. of (*i.e.*, *less* than) the mean longitude. The dates when any object near the limb will be nearest the centre, and thus most favourably situated for observation, can be ascertained from the *Nautical Almanac*, by finding the times when the favourable libration in latitude (p. 29) is about 6°, and that in longitude about 7°: the Moon, however, may be below the horizon, or the phase unsuitable.

Effects of Libration. At each recurring phase, though the positions and lengths of the shadows themselves have not changed greatly (lunar 'seasonal' changes being small, owing to the small inclination of the lunar equator to the Ecliptic, $1\frac{1}{2}°$), the Moon's latitude and longitude, &c., have altered. Libration has come into play, and we view the object and its shadow from a different position than formerly, the variation amounting at its maximum to over 20°, through the combined effect of the displacement in latitude and longitude. Except at rare intervals, therefore, we do not re-observe objects under anything like the same conditions. When viewing the Moon, it should also be remembered that it is only near the centre of the disc that we see objects in their true form and dimensions, as each object is more and more foreshortened the further it is away from the centre, and, on the limb, is seen only in profile.

The libration on any evening can be found from the *Nautical Almanac* in the 'Moon's Physical Ephemeris,' columns Earth's 'Selenographic Lat. and Long.' When the libration in longitude is +, the mean centre of the disc is displaced to the E., *i.e.*, the Mare Crisium is furthest from the limb. When the libration is −, the mean centre is displaced to the W., and the Mare Crisium approaches the limb. Similarly, when the libration in latitude is +, the mean centre is displaced to the S., *i.e.*, Plato is furthest from the limb, and *vice versa*, for −.

Best Altitude Conditions.—For any given age of the Moon, there is a certain date in the year about which more favourable altitude conditions obtain than at any other time, though it is modified to some extent by the Moon's changes in latitude. This is due to the fact that the Moon's average path coincides with the Ecliptic, so that on any given day, her altitude above an observer's horizon at culmination, will, on the average, be exactly the same as that of the Sun at noon on the date when he has similar R.A. The following Table indicates approximately the most favourable dates for observing the principal phases: (S. Hemisphere, transpose April, Oct.: and July, Jan.):—

N. Hemisphere:—	Moon 3-4 days old.	First Quarter.	Full.	Last Quarter.	25-26 days.
Most Favourable	End of April	Vernal Equinox	Winter Solstice	Autumnal Equinox	End of July
Least ,,	,, October	Autumnal ,,	Summer ,,	Vernal ,,	,, January

The Position of the Terminator on the Moon's equator, corresponding to various ages, can be approximately ascertained by means of the scale below the Map of the Moon on p. 31. It can be obtained more exactly from the 'Moon's Physical Ephemeris,' 'Sun's co-longitude' column, in the *Nautical Almanac* (in conjunction with a lunar chart having selenographic latitude and longitude lines), by using the following rule:—

Sun's Co-longitude. From:—		*Position of Terminator.*			
0° to 90°, the figures in the Table give		the terminator's longitude	E.	of the central meridian	(Sun rising).
90° to 180°, subtract the Sun's co-longit. from 180°:	answer =	,, ,, ,,	W.	,, ,, ,,	(Sun setting).
180° to 270°, subtract 180° from the Sun's co-longit.	,, =	,, ,, ,,	E.	,, ,, ,,	(Sun setting).
270° to 360°, subtract the Sun's co-longit. from 360°.	,, =	,, ,, ,,	W.	,, ,, ,,	(Sun rising).

Repetition of same Phase of illumination, near the same hour, may be expected in about 2 and 15 lunations, on the average, but there are variations—corresponding with the lengths of different lunations, which vary to and fro between $29\frac{1}{4}$ and $29\frac{3}{4}$ days. The mean lunation is just over $29\frac{1}{2}$ days, hence, on the average, in the second lunation similar phase falls in daylight; in the third, it is $1\frac{1}{2}$ hours later in the evening than the first, and so on. 1 mean lunation $= 29^d\,12^h\,44^m$; 2 lunations, $59^d\,1\frac{1}{2}^h$; and 15 lunations, $442^d\,23^h$. The mean interval from perigee to perigee, or mean anomalistic period is 27·55455 days, and does not recur at the same phase till after 14 lunations (about 1·13 yrs.), or about $1\frac{1}{2}$ months later in the following year, so that 'most favourable' conditions gradually disappear for a period.

Lunar Nomenclature. Lunar objects are generally referred to the *quadrant*, or quarter of the disc, in which they are found, numbered I to IV, as on the map. The principal formations have names of their own: other objects in the neighbourhood (also those *inside* or on a crater), not separately named, are denoted by the nearest crater name with a *Roman* letter added, for craters or depressions, or a *Greek* letter, for peaks or elevations—capitals denoting 'measured' points. Thus 'Aristoteles B' is quite different from 'Aristoteles,' being a small crater some 50 miles N. of the latter. Greek letters are also used for rills, in conjunction with the crater names.

Earthshine, popularly known as 'the Old Moon in the New Moon's arms,' is due to rays of light reflected from the Earth on the Moon's dark disc. It is stronger in the morning with Old Moon than in the evening with New Moon, and its variations are worth systematic study, as an index to the reflective power of the Earth's disc, which is lit up by the Sun. As the albedo of clouds is very high (p. viii), unusual brightness of Earthshine probably indicates that the sun-illuminated hemisphere of the Earth is much cloudier than usual, and *vice versa* when Earthshine is faint. Earthshine is best seen 3 to 5 days after New Moon in the spring, or before New Moon in the autumn, especially if the Moon is near perigee at the time, its brightness then being greatest. Earthshine is also known as '*lumière cendrée*,' or '*ashy light*.'

A very narrow ring of silver-white light, quite distinct from Earthshine, and encircling the whole lunar disc, is occasionally visible for short periods when the Moon is within 2 or 3 days of New.

Lunar Craters are classified by Neison as follows, but the classes merge gradually into one another, and near the border line either name may be used.

Walled Plains (*w* in Index), diam. 40-150 miles (65-240 km.), like *Plato*. Usually surrounded by a complex system of walls: floor usually not much lower than outside, and comparatively level; central mountain often absent. Mostly in S. hemisphere.

Ring Mountains (*mr* in Index), diam. 15-50 miles (24-113 km.), like Römer. Walls low and broken, probably ruined walled plains.

Ring Plains (*r* in Index), diam. 20-60 miles (32-97 km.), like *Copernicus*: comprise the majority of the larger lunar craters. More circular and regular than walled plains; single principal wall, generally; outer slope small, interior steep and usually terraced. Floor nearly always much lower than outside, and comparatively level. The deepest lunar formation is *Newton*, rim 23,000 feet (7000 metres) above the floor. In *Wargentin*, the floor is practically level with the top of the wall.

Crater Plains, diam. 10-20 miles (16-32 km.). Brighter, and with steeper outside slopes, than craters proper.

Craters proper (*c* in Index), diam. 5-15 miles (8-24 km.), like *Bessel*. Circular; outer slope steeper, but the interior falls more gradually than in crater plains. Floor small, with 'volcanic' cone; very bright near Full.

Craterlets, diam. 5 miles (8 km.) downward. Craters in miniature: merely a convenient sub-division, indicating very small craters.

Crater Pits, or 'Pits,' diam. as craterlets, but up to 11 miles (18 km.). Very shallow depressions, outside slope hardly perceptible. *Depressions* differ from crater pits in having no sign of walls whatever, and may be many miles or kilometers across.

Crater Cones. Steep conical peaks, diameter ½-3 miles (1-5 km.), with narrow central opening, which is very difficult to see. They appear on mountain ridges, and on crater walls and floors, and are very bright near Full. For fuller details, see the reference books, given on page 28.

Lunar 'Seas,' Valleys, &c. The Sinus Iridum, with great bordering cliffs, rising in peaks over 16,000 feet high, is one of the finest objects on the Moon; it is best seen when the Moon is 8 or 9 days old.

Of the *valleys*, the Great Alpine Valley is the most notable. Most *clefts* or *rills*, and *faults*, are not visible in small instruments, but the Cleft of Hyginus, and that of Ariadæus just W. of it, can be seen in a two-inch telescope. The 'Straight Wall,' 60 miles long and 900 feet high, is a little E. of Thebit. Pico is a solitary peak on the Mare Imbrium.

The Brightness of different parts of the Moon is an interesting study: it is valued in 'degrees,' ranging from 1°, the darkest—found in Grimaldi and Riccioli—up to 10°, found in Aristarchus, the brightest object in the Moon; Proclus is 8°. 0° is black shadow. The floor of Plato undergoes curious changes in brightness as the Sun's altitude increases.

The varying colours of the Seas may also be studied. The prevailing tint of the Maria is grey, more or less dark, Mare Crisium being the darkest (1½°-3°), with a tinge of green. The brightest of the grey plains is Lacus Somniorum (3½°-4°); Palus Somnii, equally bright, is of a yellow-brown shade. The Mare Serenitatis, the centre of Mare Humorum, and part of the Sinus Iridum, have a dark greenish colour, and the Mare Crisium a lighter green; the Mare Frigoris is a yellowish-green.

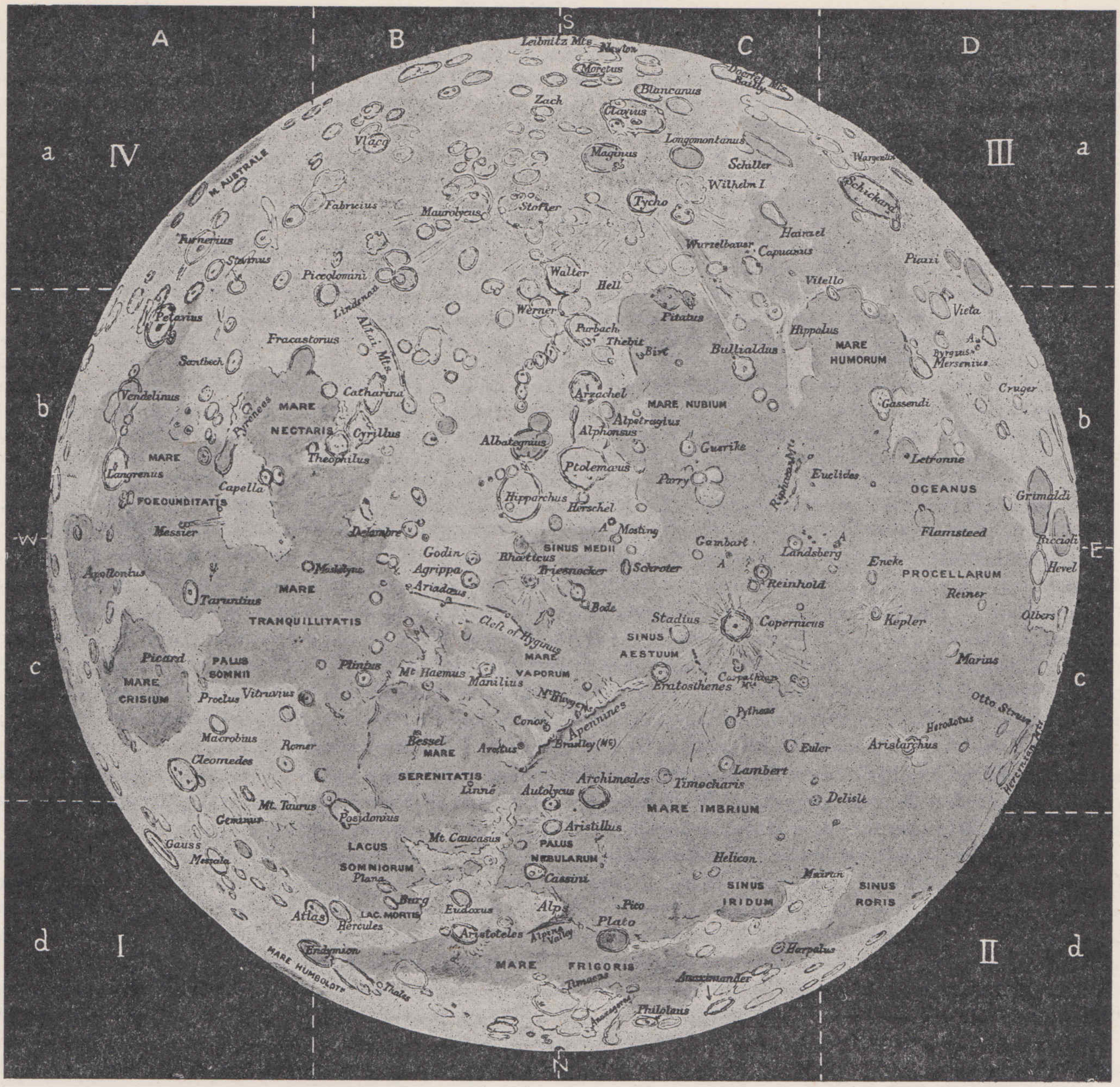
Centres of Principal Ray Systems. Aristarchus, Aristillus, Byrgius A, Copernicus, Euler, Kepler, Messier, Proclus, Timocharis, and Tycho. Euclides and Landsberg A are surrounded by a 'nimbus,' or bright patch.

The Mean Centre of the Moon, or intersection of lunar meridian 0° with the lunar equator, can always be readily found, as it is approximately the point equidistant from the three craters, Herschel, Schröter, and Triesnecker. The lunar equator is very nearly the line drawn through Rhæticus and Landsberg; lunar longitude 0°, a line drawn through the centre of Walter and the E. side of Aristillus. But see note at foot of Map of the Moon as to curved lines.

Index, Map of the Moon. The diameters, given in miles, are approximate, as authorities sometimes differ, owing to irregular shape, &c. The letters Bc, Bb, &c., indicate the square in which the object will be found. *r*, *w*, *c*, etc., see above.

	Diam.		Diam.		Diam.		Diam.		Diam.
Agrippa (*r*)	Bc 27m	Clavius (*w*)	Ca150m	Hell (*r*)	Ca 18m	Messier (*c*)	Ab 9m	Santbech (*r*)	Ab 46m
Albategnius (*w*)	Bb 70	Cleomedes (*w*)	Ac 80	Hercules (*r*)	Bd 46	Moretus (*w*)	Ca 78	Schickard (*w*)	Da134
Alpetragius (*r*)	Cb 27	Copernicus (*r*)	Cc 56	Herschel (*c*)	Cb 25	Mösting & A (*r*)	Cb 15	Schiller (*w*)	Ca113
Alphonsus (*w*)	Cb 70	Crüger (*r*)	Db 30	Hevel (*w*)	Dc 71	Newton (*r*)	Ca143	Schröter (*r*)	Cc 25
Anaximander	Cd 39	Cyrillus (*w*)	Bb 65	Hippalus (*r*)	Cb 38	Otto Struve (*w*)	Dc150	Stadius (*r*)	Cc 43
Apollonius	Ac 30	Delambre (*r*)	Bb 32	Hipparchus (*r*)	Bb 92	Parry (*r*)	Cb 25	Stöfler (*w*)	Ba150
Archimedes (*r*)	Cc 50	Delisle (*mr*)	Cc 16	Hyginus & Cleft (*c*)	Bc 4	Petavius (*w*)	Ab100	Taruntius (*w*)	Ac 44
Ariadæus (*c*)	Bc 5	Encke (*r*)	Dc 20	Kepler (*r*)	Dc 22	Philoläus	Cd 46	Thebit (*r*)	Cb 32
Aristarchus (*c*)	Dc 28	Endymion (*w*)	Bd 78	Lambert (*r*)	Cc 18	Piazzi (*w*)	Da 90	Theophilus (*r*)	Bb 64
Aristillus (*r*)	Bd 34	Eratosthenes (*r*)	Cc 38	Landsberg (*r*)	Cb 28	Picard (*r*)	Ac 21	Timocharis (*r*)	Cc 23
Aristoteles (*r*)	Bd 55	Euclides (*c*)	Cb 7	Langrenus (*w*)	Ab 85	Piccolomini (*r*)	Bb 57	Triesnecker (*r*)	Bc 14
Arzachel (*w*)	Cb 65	Eudoxus (*r*)	Bd 45	Letronne (*r*)	Db 50	Pico	Cd ...	Tycho (*w*)	Ca 54
Atlas (*r*)	Bd 55	Euler (*r*)	Cc 19	Lindenau (*w*)	Ba 35	Pitatus (*w*)	Cb 58	Vendelinus (*w*)	Ab 90
Autolycus (*r*)	Bd 25	Fabricius (*r*)	Ba 55	Linné (*c*)	Bc 2	Plato (*w*)	Cd 60	Vieta (*r*)	Db 51
Bailly (*w*)	Ca155	Flamsteed (*r*)	Db 9	Longomontanus (*w*)	Ca 90	Plinius (*r*)	Bc 32	Vitello (*r*)	Db 28
Bessel (*c*)	Bc 12	Fracastorius (*r*)	Ab 60	Macrobius (*w*)	Ac 42	Posidonius (*w*)	Bd 62	Vitruvius (*c*)	Bc 19
Birt (*r*)	Cb 9	Furnerius (*w*)	Aa 80	Maginus (*w*)	Ca100	Proclus	Ac 18	Vlacq (*r*)	Ba 57
Blancanus (*w*)	Ca 60	Gambart (*r*)	Cc 16	Mairan (*r*)	Dd 25	Ptolemæus (*w*)	Cb115	Walter (*w*)	Ba 90
Bullialdus (*r*)	Cb 38	Gassendi (*w*)	Db 55	Manilius (*r*)	Bc 25	Purbach (*w*)	Cb 70	Wargentin (*r*)	Da 54
Burg (*r*)	Bd 28	Gauss (*w*)	Ad110	Marius (*r*)	Dc 27	Reiner (*r*)	Dc 21	Werner (*r*)	Bb 45
Byrgius, & A (*r*)	Db 40	Godin (*c*)	Bc 23	Maskelyne (*r*)	Bc 19	Reinhold (*r*)	Cc 31	Wilhelm I. (*w*)	Ca 46
Capella (*r*)	Ab 30	Grimaldi (*w*)	Db147	Maurolycus (*w*)	Ba 75	Rhæticus (*r*)	Bc 25	Wurzelbauer (*w*)	Ca 50
Capuanus (*r*)	Ca 34	Hainzel (*w*)	Ca 55	Mersenius (*r*)	Db 41	Riccioli (*w*)	Db106	Zach (*w*)	Ba 46
Cassini (*r*)	Bd 36	Helicon (*r*)	Cd 13	Messala (*w*)	Ad 69	Römer (*mr*)	Ac 30		
Catharina (*w*)	Bb 70								

SKETCH MAP OF THE MOON. (As seen in an inverting Telescope)



SCALE SHOWING APPROXIMATE POSITION OF THE TERMINATOR ON THE MOON'S EQUATOR AT VARIOUS AGES.

Young Moon Age, dys.	0	1 dy	2 dys.	3	4	5	6	7	(1/4)	8	9	10	11	12	13	14 d.
Old Moon	15	16	17	18	19	20	21	22	(3/4)	23	24	25	26	27	28	29

In using this or any other Map of the Moon, it must be remembered that :—

(*a*). Objects very near the limb in the Map may be completely out of sight or much foreshortened, owing to libration. The Mare Crisium and Grimaldi for instance, almost touch the edge at extreme libration.

(*b*). The lunar equator, and parallels of latitude, which are straight on the Map, are only seen thus when the libration in latitude is 0°, *i.e.*, when the lunar axis is in the position of mean libration ; at other times these lines are seen as ellipses of greater or less curvature, curved southwards when the libration in latitude is +, and curved northwards when the libration in latitude is −.

(*c*). Similarly the meridian of lunar longitude 0° is only seen as a straight line when the libration in longitude is 0° ; at other times it also is elliptical, convex W. or E. according as the Moon's libration is − or +.

(*d*). The mean centre of the disc is only seen in the centre when the libration in longitude and latitude are each 0°. At other times it may be displaced up to 7° 45′ in longitude and 6° 44′ in latitude, or as the combined result 10° 16′. The Moon's libration in longitude is 0° about perigee and apogee, and her libration in latitude about 0° when she is crossing the Ecliptic.

When the Moon's libration in longitude is −, the region exposed to view is on the E. limb, & Mare Crisium is nearer the limb, than mean position.
" " " + " " " W. " " " further from " " "
When the Moon's libration in latitude is − " " " S. limb, & Plato is nearer the limb than mean position.
" " " + " " " N. " " further from " "

LUNAR MOUNTAINS, &c.

		Height, ft.			Height, ft.
Alps,	Bd	12,000	Dœrfel Mts.	Ca	26,000
Alpine Valley	Bd	...	Hæmus Mt.	Bc	8,700
Altai Mts.	Bb	13,000	Leibnitz Mts.	Ba	30,000
Apennines	Cc	18,500	Pyrenees	Ab	12,000
Bradley, Mt.	Bc	13,600	Riphæan Mts.	Cb	2,700
Caucasus	Bd	18,500	Taurus Mt.	Ad	10,000

LUNAR SEAS (OR 'MARIA'), &c.

Mare Australe ...	Aa	Mare Nectaris ...	Ab	Lacus Somniorum	Bd
" Crisium ...	Ac	" Nubium ...	Cb	Palus Nebularum	Bd
" Fœcunditatis	Ab	" Serenitatis ...	Bc	" Somnii	Ac
" Frigoris ...	Cd	" Tranquillitatis	Ac	Sinus Aestuum ...	Cc
" Humboldtianum	Ad	" Vaporum ...	Bc	" Iridum	Cd
" Humorum ...	Db	Ocean. Procellarum	Dc	" Medii	Cc
" Imbrium ...	Cd	Lacus Mortis ...	Bd	" Roris	Dd

THE PLANETS.

The Nautical Almanac (**N.A.**), and **The American Ephemeris** (**A.E.**), give much useful planetary observing information. Under 'Phenomena' are the dates of opposition, conjunction in R.A. with the Sun and Moon, elongations of Mercury and Venus, &c.; there are Occultation Tables, with latitude-limits of observability, and those seen at certain stations; also Sunrise, Sunset, Moonrise, Moonset, and Twilight Tables, for latitudes 0° to 60°. The 'Physical Ephemeris' Tables give the position angle of the axis, planetary meridian on the centre of the disc, magnitudes, configuration and eclipses of the satellites, &c.; also:—

Mars and Jupiter. The angular amount of phase, (always on the W. side from conjunction to opposition, and on E. side from opposition until conjunction) is given by column q; the linear (=areal) fraction of the disc illuminated, by column k. Column D⊕ gives the number of degrees the planet's N. pole (+), or S. pole (−), is turned towards the Earth: maximum about 25½° for Mars; 4° for Jupiter; 29° for Saturn; but largely nullified by foreshortening. 0° = both poles on limb.

Jupiter's Satellites. Configuration: ○ at the side indicates 'In transit'; ● 'In occultation or eclipse.' The Phase diagrams show the position of each satellite during the month by a * (change slight, except near opposition), of the points where the satellites disappear in, or emerge from the shadow†; c (or d) is the point of disappearance; f (or r), that of reappearance.

Saturn's Rings. Column B (Saturnicentric latitude of the Earth) gives the angular 'openness' of the rings, 0° when invisible, about 28° fully open. Column B' is the Sun's elevation above the ring-plane; the rings are invisible when B or $B'=0°$; and also when B (Earth) is + (North), and B' (Sun) is − (South), or *vice versa*. Position angle of axis is same as column P.

Hour of R.A. on the meridian at mean midnight (Sidereal Time), for each day; from this, that at other hours can be found.

Rising or Setting of Planets. From the *N.A.* time of meridian passage, subtract (or add) the semi-diurnal arc (see p. xiv).

Astronomical Terms; The Calendar. The student should read the very interesting article on these subjects in the Appendix to the British *N.A.*, which also contains, for the advanced, an elaborate *precis* of formulæ used in the Almanac.

Heliocentric longitudes and latitudes, and radius vectors, giving orbital positions and distances with reference to the Sun, are given annually in the *American Ephemeris*. The British *N.A.* publishes them for twenty years in advance, 1917-40 in *N.As.* 1915-17 (Mercury annually, till 1938): 1941-60, also 1900-1940, in special vols. Earth's heliocentric longitude, see p. 4.

General Notes.—The *Major Planets*, so called to distinguish them from the *Asteroids* or *Minor Planets*, none of which exceeds a few hundred miles in diameter, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto. The first four, and Pluto, are sometimes distinguished as the *Terrestrial Planets*, as their sizes are comparable with that of the Earth, the others as the *Giant Planets*. They are always near the Ecliptic except Pluto, within the Zodiac (p. 3), and are readily distinguished from fixed stars, as they do not twinkle unless low down; their spectra are those of reflected sunlight, with bands due to methane in all the giant planets, and ammonia in Jupiter and Saturn (p. 35). Their constantly-changing positions are easily found by the R.A. and Declination given in almanacs.

Unlike the Moon, which souths about 38 to 66 minutes (mean, 50½) later each day, the *Superior Planets* (Mars, the Asteroids, Jupiter, and those beyond) south earlier, on the average, each night, appearing to move nearer the Sun daily when E. of him, but further away when W. of him, and being lost in his rays for some six weeks annually—Mars, and the asteroids in general, for months, biennially, having long synodic periods (see below).

The Superior planets are best seen when in opposition, southing about midnight; the *Inferior Planets* (Mercury, Venus), about the times of greatest elongation. Opposition or greatest elongation may occur at any time of the year, but the nearer they happen to one date in a certain month (Superior planets, that on which the Earth's heliocentric longitude is about the same as that of the planet's perihelion) the larger and brighter is the planet; many years, however, elapse before the most favourable conditions recur. For Magnitude variation, see pp. 17 and 41.

The Solar System (see also p. viii).—The figures below are mostly (or, based on) those of the *American Ephemeris*, to which refer (or to the yearly *B.A.A. Handbk.*) for greater precision. The larger of two diameters is the equatorial, the smaller the polar.

Sun. Diameter, 864,400 miles, 1,391,100 km.; **Moon**, 2160 miles, 3476 km. **Density:** (water=1) Sun, 1·41; Moon, 3·34.

Planets.	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Sun	Moon
Angular diameter, Max.	12″·9	64″·0	...	25″·1	49″·8	20″·5	4″·2	2″·4	...	32′ 36″	33′ 31″
,, ,, Min.	4″·7	9″·9	...	3″·5	30″·5	14″·7	3″·4	2″·2	...	31′ 31′	29′ 22″
,, At Mean Dist.	6″·7	16″·0	...	6″·1	37″·9	17″·3	3″·8	2″·3	...	31′ 59″	31′ 5″
Oblateness or ellipticity	0	0	1/297th	1/192nd	1/15·4	1/9·5	1/14th	1/40th	...	0	0·0006
Mass, Earth=1	0·04	0·81	1·00	0·108	316·94	94·9	14·66	17·16	0·83	332,000	0·012
,, Sun=1	1/8-millionth	1/403,490	1/329,370	1/3-millionth	1/1047	1/3502	1/22,869	1/19,314	1/400,000	1	...
Axis‡ or Equator, Inclination to orbit	...		23°·45	25°·17	3°	26°·7	98°	151°	...	7°·17§	6° 41′

Mean Distance from Earth:—*Inferior planets*, 1 Astron. Unit; *Superior*, =mean distance from Sun; mean opp'n distance, 1 unit less Aphelion and Perihelion Distances, $=a \pm a \times e$, when a=the semi-major axis (the Mean distance) in A.Us., and e the eccentricity.

Planet (Symbols, see p. xii)	Mean Distance fr. Sun. Astron. Units	Millions of:— Miles	Kilom.	Diameter Thousands of:— Miles	Kilom.	Density Water =1	Sun =1	Mean Periods. Sidereal, in years	Synodic, in years	Axial Rotation	Orbit: Epoch 1950. Eccentricity	Inclin. to Eclipt.	Longit. Asc. node	Longit. peri helion	Mean Motion (Sidereal) Daily	Yearly
Mercury	0·387	36·0	57·9	3·0	4·83	3·7	2·6	0·2408	0·3173	88 days?	0·2056	7°·00	47°·7	76°·7	4°·09	...
Venus	0·723	67·2	108·1	7·57	12·18	5·2	3·7	0·6152	1·5987	225d? 68h?	0·0068	3·40	76·2	130·8	1·60	...
Earth	1·000	92·9	149·5	7·927 7·90	12·76 12·71	5·5	3·9	1·00004	...	23h 56m 4s	0·0167	0°	...	102·1	0·99	360°
Mars	1·524	141·5	227·8	4·2	6·76	3·9	2·7	1·8809	2·1354	24h 37m 23s	0·0934	1·85	49·1	335·1	0·52	191½
Eros (433)	1·46	134·8	217·9	0·015	0·024	...	...	1·723	2·3031	5¼h	0·2229	10·84	303·6	121·9	0·54	209°
Jupiter	5·203	483·3	777·8	88·7 82·8	142·7 133·3	1·3	0·9	11·8622	1·0921	9h 50-55m	0·0484	1·30	99·9	13·5	0·08	30¼
Saturn	9·539	886·1	1426	75·1 67·2	120·9 108·1	0·7	0·5	29·4577	1·0352	10h 14-38m	0·0557	2·49	113·2	92·1	0·03	12¼
Uranus	19·19	1783	2869	30·9	49·7	1·4	0·9	84·0153	1·0121	about 10¾h	0·0472	0·77	73·7	169·9	0·01	4¼°
Neptune	30·07	2793	4496	32·9	52·9	1·3	0·9	164·788	1·0061	15h 40m	0·0086	1·78	131·2	44·2	0·006	2⅛°
Pluto	39·46	3666	5899	3·0?	4·8?	...	...	247·697	1·0047	...	0·2485	17°·14	109°·6	223°·5	0°·004	1¼
... ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

† Direction of motion is towards the figures. ‡ For the axis, to the *vertical* to orbit. § To Ecliptic (Moon, 1½°).

The Paths of the Planets on the Star Sphere. As seen from the Sun, these (their heliocentric paths) are, for ordinary purposes, unchanging, and each intersects that of the Earth (the same as the Ecliptic) at two practically fixed points, the nodes. The heliocentric paths are also approximately the average paths of the Superior planets, as seen from the Earth (see below).

Planets attain their greatest heliocentric latitude when about 90° longit. from the nodes, and remain longest (lengthens as the eccentricity) on that side of the Ecliptic in which aphelion lies than in the other, partly because the node-aphelion-node distance is greater (slightly, unless eccentricity is great), partly because the mean motion is slower. If the node-perihelion angle (ω) is *greater* than about 180°, aphelion is in the N. celestial hemisphere (Mars, Jupiter, Saturn, Neptune); if *less*, in the Southern (Mercury, Venus, Uranus, Pluto); in the former, the altitude at favourable oppositions is best for Southern, in the latter for Northern observers.

As seen from the Earth, the *Superior planets* reach a latitude above or below the Ecliptic at least equal to the inclination of their orbits, and each follows the heliocentric path more and more nearly the less its parallax—*i.e.*, the remoter the planet is from the Sun; thus their geocentric paths are confined to a very narrow strip on the star sphere—Mars excepted (see below).

Mercury and Venus, which circle the star sphere with the Sun, have the Ecliptic for their average path (approx.), and attain 5° and 9°, respectively, from it if max. heliocentric latitude occurs with Earth about heliocent. longit. 318° (*Merc.*), 166°, 346°(*Venus*).

The Earth's everchanging position in her orbit, may, as seen from her centre, displace the Superior planets from their heliocentric positions (*a*) E. or W. by an amount about equal to the Earth's *annual* parallax (p. 14) as seen from the planet; (*b*) N. or S. by a small amount—greatest about perihelion opposition, smallest about conjunction—except for near-by Mars, which at opposition may be some 3° to 5° N. or S. of the heliocentric path; Jupiter's maximum is about ¼°. And as the Earth's mean daily orbital motion of 1° exceeds those of Mars and the asteroids by ½° or more, and those of the other Superior planets by well-nigh 1°, (see Table, p. 32), when Earth and planet are on the same side of the Sun and in the same line, at opposition, the Earth outruns the planet, causing it apparently to retrograde on the star sphere—before and after opposition, also, for some time. The combined motions of the Earth and a planet make the latter's path on the star sphere, as seen from the Earth, a looped or zigzag curve.

Mercury is always so close to the Sun that, even when most favourably situated, he is only observable for about two hours (naked eye, ½ hr,) after sunset or before sunrise, and that at a very low altitude, especially in higher latitudes. His very eccentric orbit causes his greatest elongation (G.E.) from the Sun to vary from 18° to 28°—the latter one being at aphelion, when he is S. of the Celestial Equator, and best seen by Southern observers. In temperate latitudes he is most favourably placed near the Equinoxes, as an evening star in spring, some days before G.E.—one in April being best, or as a morning star in autumn, some days after G.E. (in the S. hemisphere, Oct. and April).

Mercury has phases like the Moon, and is mag. – 1·8 when in perihelion near superior conjunction (but very near the Sun); at G.E., the average is only + 0·2. Sidereal period 88 days; synodic, about 116 dys. (Rotation, see below).

Venus, the brightest of the planets, sometimes seen in broad daylight, may even cast a shadow; her faint markings (very doubtful if permanent features) are difficult to observe owing to lack of contrast, but her phases can be studied in a small telescope or good opera glass; examine in daylight—which diminishes the glare—or soon after sunset or before sunrise. Her greatest brilliancy is during the crescent stage—as an evening star about a month after, or as a morning star *before*, greatest elongation, which at maximum is 47°. (G.E. never occurs at nearest to Earth).

The maximum magnitude (– 4·4) occurs about every 8 years, when Venus is in perihelion near the end of December, and S. of the Celestial equator as a morning star, therefore more favourably situated for Southern observers; she is then twelve times brighter than Sirius; she is slightly fainter when in perihelion about the middle of March as an evening star, when Northern observers see her much higher above the horizon. Her apparent motion is so slow—the synodic period being about a year and seven months (584 days)—that she remains visible or invisible for several months, unlike Mercury, which rapidly disappears in the Sun's rays. Sidereal period, 224·7 days; rotation, see below.

A faint luminosity, like Earthshine on the Moon, occasionally reported as visible on the dark side, is now attributed to ocular causes.

Recurrence of Greatest Elongation.—For Mercury, the most favourable elongation occurs about every six years; for Venus about every 8 years. The intervals between greatest E. and W. elongation are very unequal :—

Greatest E. to greatest W. elongation, inferior conjunction between :—Mercury about 44 days; Venus 144 days.
„ W. „ E. „ superior „ „ „ „ 72 „ „ 440 „

Mars is of little interest in a small telescope except in or near opposition—when his angular diameter is 13″ to 25″; this occurs every 780 days on the average—nearly two years and two months, the longest (major) planetary synodic period; the sidereal period is 687 days. Favourable oppositions come every 15 or 17 years, the best about Aug. 26th (from 1924, very favourable), when Mars exceeds Jupiter in brightness, attaining mag. – 2·8, but as his disc is even then only half the diameter, little detail is seen in small telescopes. The mean and minimum opposition magnitudes vary between – 2·25 and – 1·0, while in conjunction with the Sun he is only 2nd magnitude. Except near opposition, Mars is more or less 'gibbous'—*i.e.*, not fully, but more than half-illumined—greatest when he is in quadrature (90° longitude, or 6 hrs. R.A. from the Sun); only 0·84 of the disc is then illumined. Mars has two tiny satellites.

On Mars' ruddy disc, dark greyish-green markings—once thought to be seas, but now supposed to be marshes or vegetation areas—can be seen, and one or other of the bright, white polar spots (probably snow-caps, perhaps partly hoar frost) is a striking feature; occasionally both caps are visible. The finer so-called 'canals'—an unfortunate translation of Secchi's *canali*, 'channels,' not necessarily artificial—are invisible in small telescopes, and though some seem to result from real markings, the tendency is to regard them as partly due to ocular causes. Rotation period, 24h. 37·4m.

Rotation Periods of Mercury and Venus.—*Mercury's* rotation period is now believed to be 88 days, the same as his sidereal one, so that he always keeps the same face to the Sun. *Venus* is still a puzzle; the period of 24-hrs. or so, long accepted, is now abandoned, the bulk of the evidence indicating a period greater than 20 days, while some think she rotates in the same time as her sidereal period, like Mercury. Pickering's period is 68h., axis inclined only 5° to the orbit.

Jupiter is a fine object for small telescopes, with his elliptical disc, darker at the edges than in the centre, and 'parallel belt' markings; when in quadrature (p. 5) the limb is very slightly shaded, owing to 'phase.' The rotation period is 9h. 50·5m. near the equator (System I., *N.A.*), and 9h. 55·7m. in the temperate zones (System II.).

For reference, the disc is divided into the *N. and S. Polar Regions*; the *Equatorial*, *Tropical*, and *Temperate Zones*, crossed by seven darker 'belts'—viz., the narrow *Equatorial Band*; the *Equatorial* (*N.* and *S.*), and *Temperate* (*N.*, *NN.*, *S.*, *SS.*) *Belts.*

The Great Red Spot, seen in 1857, first prominent in 1878, was an oval about 13″ by 3″ (30,000 by 7000 miles), and its rotation period has varied by several seconds. Bright red till 1881, by 1892 it had faded to a pale orange, and has since shown little colour. In 1919-20, remarkable and rapid changes occurred in this region, the Spot disappearing and re-appearing again. It has generally been seen in a 'hollow' or 'bay' in the S. side of the S. Equatorial Belt, and a dark marking, the *S. Tropical Disturbance*, periodically overtakes the Spot and accelerates its motion.

Jupiter's synodic period being about 399 days, in successive years oppositions take place a month later in the season, the most favourable being every 12 years, in Sept.-October; his magnitude is then – 2·5, compared with about – 2·3 at mean opposition. Minimum mag., when in conjunction with the Sun, about – 1·2. Sidereal period, 11·86 yrs.

Jupiter's Satellites or Moons.—Seven of these are seen only in great telescopes or on photographs. The other four (about mag. 6, and numbered from the planet I, II, III, IV) are visible in an opera glass: they are all eclipsed by Jupiter's *shadow* (not instantaneously), I to III once every revolution. Sometimes a satellite 'transits' or passes across the planet's disc, appearing, as it enters or leaves the disc, as a bright spot on a dark background (the limb or edge of the planet being darker than the centre), while later it may disappear, if the background is similar in brightness and colour; it may also show as a dark spot. The shadow also transits the disc as a dark spot, which is apt to be taken for the satellite itself; sometimes both satellite and shadow are seen transiting at the same time.

Occultations, when the satellites pass behind the *body* of the planet, are frequent, but of little interest, though, when Jupiter is in or near quadrature, the satellite may disappear, or re-appear, slightly away from the apparent limb owing to the 'phase'—which is on the west side before, and on the east side after, opposition.

Saturn is also a fine object for small telescopes. The disc is even more elliptical than that of Jupiter—seen fully only when the Earth is in the plane of the rings—but is only slightly darker at the edges than in the centre. Faint parallel-belt markings may be discerned, and occasionally bright or dark spots, but his special feature is the wonderful Ring system, divided in two by a dark line-like marking known as *Cassini's Division*; it is just visible in a 2½-inch refractor when the rings are fully open. The projecting ends of the rings are called the *Ansæ*; the one facing in the direction of the planet's motion, in the field of view, is the 'preceding' ansa, the other the 'following' one.

The principal rings are designated A (the outermost) and B which is brighter; A is divided by a narrow dark line known as *Encke's Division*, not easily seen. A third ring C, the dusky *Crape*, *Crepe*, *or Gauze Ring*, nearest the planet, requires at least a 4-inch telescope. The rings are not solid as was once supposed, but myriads of tiny bodies revolving round the planet; the actual thickness of the rings is not yet known; estimates vary from 10 to 50 miles.

Saturn Ringless.—Twice in the course of Saturn's 29½-year sidereal period, at intervals of 13¾ and 15¾ years (from 1936), the rings present their edge (*a*) to the Sun, (*b*) to the Earth, or (*c*) turn their unillumined side towards the Earth, and become invisible in ordinary telescopes—even in the largest telescopes, when edgeways to the Earth—for a day or two; Saturn is then in heliocentric longitude 172° or 352°, in the constellations Leo or Aquarius-Pisces. About 8-7 years later, when he is in the constellations Taurus or Sagittarius (long. 82° and 262°) the rings are fully open, and he is at his brightest (see p. 17). The most favourable conditions for brightness and openness are when Saturn is in opposition at the times of perihelion (longitude 91°), and greatest openness, which, for the same longitude, only occurs every 29-30 years (from 1943). The Earth is in longitude 82° and 91°, about Dec. 15 and 24, with Saturn N. of the Ecliptic, and in 262° about June 14, when he is S. of it: oppositions about these dates will therefore be favourable, but those in the observer's summer will be at low altitudes. As Saturn's synodic period is 378 days, oppositions recur only a fortnight later in the season each year, giving for some years a succession of the best brightness-conditions. At the time of ring-invisibility, the Earth may pass (or almost pass) through the ring-plane thrice in the course of a year, the central one being near longitude 172° or 352°, the others months before or after (see Table p. viii).

Saturn's magnitude varies with the apparent width of the rings; mean opposition about + 0·93, max. – 0·4; ringless, from 0·65 to 0·87. His rotation period varies with the latitude, averaging about 10½ hours. Herschel I. gives it as 10h. 16m.; Hall (1876) 10h. 14m. 24s., for lat. 10°; Denning (1903) 10h. 37m. 56s.* Sidereal period, 29·46 years.

Saturn has nine satellites; a very small telescope shows Titan, the brightest (mag. 8·3); a 3-inch, or even less, Rhea (mag. 10·0); a 4-inch, Tethys, Dione, and Iapetus (mags. 10·6, 10·7, 10·9, respectively); the others are mag. 12-15.

Uranus and Neptune are of little interest to the ordinary observer, being so distant that their small discs are visible only in telescopes over 4 inches, their satellites in large ones. Uranus, being mag. 6, is visible to the naked eye; Neptune, mag. 7, in an opera glass. Their maximum and minimum brightness differ only by about 0·5 and 0·2 magnitude, respectively: their angular diameters also vary very little. Uranus has four satellites, Neptune one.

Pluto, discovered 1930, has a very eccentric and highly-inclined orbit (17°); at perihelion (in 1989) he comes nearer the Sun than Neptune. His magnitude (seems variable, by 0·2-0·4 mag.) ranges from about 12¾ to 15¾. His diameter and mass, as determined by Prof. Brouwer of Yale from perturbations of Neptune, is about equal to that of Venus.

* In the Planet's north latitude 35°.

Planets X, O, P, &c. Ultra-Neptunian planets, suggested by planetary perturbations and cometary analysis. Pluto represents Lowell's 'Planet X' (1915, mass much less); for the others, see *H.A.*, vol. 61, *P.A.*, vol. 40, 1932.

The Asteroids, or Minor Planets, being very minute, are all invisible to the naked eye, except *Vesta* (oppos. mag. $6\frac{1}{2}$); the largest *Ceres*, is 480 miles in diameter, but the great majority are well under 50 miles. They occupy the position where 'Bode's Law' (p. viii) indicates a planet ought to exist, and may possibly be the remains of one. Unlike the Major planets (except Pluto), their orbits vary greatly in inclination to the Ecliptic and in eccentricity *Hidalgo* (944) having an orbit-inclination of 43°, and an eccentricity of 0·65 (exceeded by that of *Adonis*, see below).

New asteroids may receive names, but are only numbered (symbolised thus, ③, roughly in the order of discovery) when a satisfactory orbit has been obtained: for the temporary nomenclature, see p. ix. Over 1300 asteroids are now known.

Eros (433), diameter about 15 miles, and perhaps 8-shaped, or irregularly coloured, as its light varies, rotates on its axis in $5\frac{1}{4}$ hours. Its orbit is so eccentric that when nearest the Earth it is about half the least distance of Venus, or 14 million miles; it is then about mag. 7, but is usually beyond the reach of small telescopes, the mean opposition magnitude being mag. 10. The nearness of Eros makes it of great importance for accurate measurement of the Sun's distance.

Amor (Delporte Planet 1932 EA), not more than 3 miles in diameter, approaches within about 10 million miles of the Earth—4 million miles nearer than Eros does. It may be in opposition twice in a year. Period about $2\frac{3}{4}$ years.

1932 HA, the Reinmuth planet, about a mile in diameter, may transit the Sun, its orbit coming within that of Venus; it may be only 3 million miles from the Earth. Period about $1\frac{3}{4}$ years. (No name or number, orbit doubtful).

*Adonis** (*1936 CA.*, also unnumbered), a second Delporte planet, approaches nearer the Earth than any other known body except the Moon; in 1936, it was only 1·38 million miles from us. In addition, its eccentricity (0·76) is greater than that of any other planet, so that it comeswell within the orbit of Venus, and travels out as far as that of Mars. It is probably under half a mile in diameter. Period about 2·57 years; inclination of orbit, 1°26′.

The *Trojan* (or *Jupiter*) *Group* of asteroids, named after heroes in the Trojan war, is noteworthy for its members revolving in stability equidistant (approx.) from the Sun and Jupiter, though their orbits are very near that of the latter

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Planetary Radiation†.—*The Insolation* of a planet is the total radiation it receives from the Sun; of this the planet *(a)* reflects much solar radiation of short wave-length, *i.e.*, the ultra-violet, visible, and shortest infra-red wave-lengths up to say $1{\cdot}4\mu$ ($=\lambda 14{,}000$); and *(b)* absorbs the rest, then re-radiates it as *Planetary Radiation* of long wave-length, *i.e.*, invisible low-temperature heat-rays, which may include the planet's own radiation, if any: thus *(b)* is the measured total radiation *less* the amount of *(a)*. A 1cm. water cell placed in the beam of the planet's radiation transmits (*a*) but absorbs (*b*), thus enabling the amount of the latter to be measured. As an atmosphere acts as a blanket, the planetary radiation of atmosphereless planets will be high; that of those with atmospheres will tend to be small, lessening the denser and cloudier the atmosphere. Quartz and fluorite screens, which transmit longer wave-lengths than the $1{\cdot}4\mu$ of the water-cell (to $4{\cdot}1\mu$ and 12μ respectively) are also used in these investigations.

Jupiter and Saturn emit 6 per cent of planetary radiation; Mars has about 50%, indicating a thin atmosphere; Venus, about 8% on the bright side. The Moon and Mercury give 74%, suggesting similar physical (atmosphereless) condition. The Moon's local radiation at first or last quarter is proportional to the distance from the illuminated limb, and is zero at the terminator. The difference in the radiation from the light and dark lunar areas is slight.

Planetary Temperatures.—The surface-temperature of the Moon varies greatly throughout the lunar day; under the vertical Sun it is 101°C. (214°F.), while during the long night it sinks to less than −150°C. (−238°F.). *Mercury* under the vertical Sun is about 685°K. (412°C., 774°F., above the melting point of lead), at perihelion, and 555°K. (282°C., 540°F.), at aphelion; his dark side must be very cold, practically no heat being measurable. *Venus* differs little on the bright and dark sides, her temperature being about −23°C. (−9°F.); we evidently only see the upper surface of a cloud-layer in the isothermal region. *Mars*, under the vertical Sun, is 21°C. (70°F.) at perihelion, but only −6°C. (21°F.) at aphelion, when the temperature at the poles is about −70°C. (−94°F.). *Jupiter* and the other giant planets are evidently cloud-covered like Venus, but their temperatures are naturally lower, Jupiter being about −130°C. (−202°F.); *Saturn*, though much further from the Sun, some −120°-150°C. (−184°-238°F.), thus seemingly emitting some heat of his own; *Uranus* and *Neptune*, some −190°C. (−310°F.) and −220°C. (−364°F.) respectively.

Planetary Atmospheres.—The Asteroids, the Moon, and even Mercury (probably, the temperature being high) having masses too small to overcome the 'velocity of escape' (p. 24), are atmosphereless. If Mercury has an atmosphere as faint transient markings (perhaps dust from volcanoes) suggest, it is so tenous that the solar spectrum is unaffected.

Venus has carbonic acid gas in her atmosphere, but seemingly no oxygen or water vapour in the observable regions.

Mars.—The density of his atmosphere at ground surface is estimated as not exceeding that of the Earth at a height of 11 miles, but it is probably much less; clouds form in it and disappear, and both oxygen and water vapour are believed to be present, and were reported as having been observed in 1924, but later observations failed to confirm them.

The Giant Planets' atmospheres, so far as they are penetrable, are probably largely composed of hydrogen, and all contain the not easily condensed methane (marsh-gas, CH_4), the quantity increasing the further the planet is from the Sun's warming radiation. Jupiter, with the highest temperature, and to a lesser extent Saturn, also contain ammonia.

Pluto, if similar to Mercury, could retain an atmosphere, but the very low temperature would condense most gases.

* *Ant er'os*, temporarily. † See Lowell Obs. Bulletin, No. 85, 1925.

Planetary Surfaces.—Only the cloudy upper regions of the Giant planets and of Venus are visible, but the actual surfaces of the Moon, Mercury, and Mars, are seen. The polarimeter curves of the three latter are strikingly similar to those of volcanic ash and pumice. From their albedos at different phases, the surfaces of Mercury and the atmosphereless Moon seem to be very similar, as might be expected, and are rather rough; that of Mars seems to be fairly smooth.

Meteors or Shooting Stars are of all degrees of brightness, from the faintest, lasting an instant, to the *bolide* or brilliant *fireball*, lasting several seconds: those that reach the Earth are called *aerolites*. Meteors may appear in any part of the sky, but there are certain well-marked points on the star sphere from which showers of meteors come every year at regular dates, when the Earth returns to the same part of its orbit. These showers are named from the constellation in which lies their *Radiant Point* or *Radiant*—so called because the meteors of the shower appear to radiate in all directions from that point in the sky. Many hundreds of radiants are known; the Table on p. 43 gives a few of the principal showers that may be looked for, and the approximate position of their Radiants. Those interested will find a long list in Webb's 'Celestial Objects.' In colour, the average meteor is more or less white, and is estimated to weigh not more than a single grain, from brightness and velocity considerations.

The meteors for any particular radiant mostly exhibit the same general characteristics year after year. There are, however, considerable differences between various showers. In some, the meteors move very swiftly, in others, they move comparatively slowly; in some, the average meteor is faint, in others, a proportion of fireballs may be expected. Streaks or trails are characteristic of some showers, while occasionally a bright slow-moving meteor seems to travel in a wavy path. All these points should be noted in meteor observations, but in recording the appearance of a meteor, the unskilled should note that it is much more important to describe exactly its apparent path or track among the stars, from beginning to end, than its physical appearance. The same shower may also vary considerably in point of numbers, being quite conspicuous one year, and hardly visible the next, or for years in succession. On the other hand, some showers of considerable steadiness sometimes flash into great activity at intervals, the Leonids for instance.

Meteors are generally twice as frequent at 6 a.m. as at 6 p.m., because at the former hour we are facing in the direction of the Earth's motion in its orbit; in the latter, to the rear. They usually appear from 50 to 80 miles above the Earth's surface, and, on the average, disappear at 40 or 50 miles. (See Notes on observing meteors, p. 43).

Comets vary in brightness, most of them being visible only with the aid of a telescope. A comet is generally first discernible as a minute, faint, misty patch of light, so much resembling a nebula that it is only identified as a comet when found to be in motion, but sometimes even a very large comet escapes detection at first by approaching us in the line of the sun. The essential portion of all comets is the *coma* or head, the misty patch of light already mentioned. In addition a *nucleus* may develop as it approaches the sun, *i.e.* a bright flame-like or star-like appearance within the *coma*, and also a tail, or sometimes several tails—which always point more or less away from the sun, no matter whether the comet is approaching or receding from the sun. The tail usually appears as a curved hollow cone, decreasing in brightness as it widens out. Both nucleus and tail, when present, increase in size and brightness as the comet nears the sun, and decrease as it recedes from the sun; *envelopes*, or stratifications of the mist round the nucleus, especially on the side towards the sun, may also appear as the comet approaches perihelion. Neither nucleus nor tail, however, is necessarily present. Several comets are connected in some way with meteoric showers.

Periodic comets—those which revolve round the sun, and thus appear at regular intervals—are known by the name of their discoverer (as *Holmes' comet*), or discoverers at two different returns (as *Pons-Brook's comet*), or discoverer or investigator of the periodicity (as *Halley's* and *Encke's Comets*). Tempel I (1867), Tempel II (1873), indicate two discoveries by the same observer. *Biela's comet* (now lost), which divided in two, was known as Biela I and II.

The Zodiacal Light:—Except near the time of the equinoxes, this is not well seen in temperate latitudes, as its axis in the sky at other times is comparatively near the horizon. It appears as a faint, hazy, conical, beam, some 15°-20° wide at the base, which nearly follows the course of the Ecliptic (not the Celestial Equator) on the star sphere, for 90° or more from the horizon a little south (S. Hemisphere, north) of where the Sun is below the horizon; in its brightest parts, it is two or three times as luminous as the Milky Way, but towards its extreme limits it is always exceedingly faint. Its brightness seems to vary from time to time, and it is brighter when observed within the tropics than in temperate latitudes, partly owing to its being more nearly vertical to the horizon, and partly to the shorter duration of twilight. It is best seen Feb.-March (evening), Aug.-Sept. (morning) in the N. Hemisphere; in the S. Hemisphere, *vice versa*; the inexperienced are apt to mistake the glow of twilight for it. (See Notes on Observing). In a very clear atmosphere, the *Zodiacal Band*, a narrower extension, joins the *Gegenschein* (next page), thus extending the Light right round the star sphere. These phenomena are all usually attributed to sunlight reflected from meteoric bodies, their spectra being mainly that of sunlight, but two recent theories consider them, (*a*) a terrestrial 'tail,' like that of a comet, due to the Sun's light-pressure; (*b*) an atmospheric phenomenon at an immense altitude.

The 'Counterglow' or Gegenschein is a *very* faint round patch of light, 10°-20° in diameter (*i.e.*, larger than the 'Great Square of Pegasus' = α, β, γ, PEGASI and α ANDROMEDÆ), or 40°-60° according to another authority, situated on the Ecliptic at the point diametrically opposite to where the Sun is for the time being. It is very difficult to see, and cannot be distinguished if projected on the Milky Way: choose a moonless night of exceptional clearness, when the Ecliptic is highest above the horizon, viz., in December and January. According to Barnard, it is largest and brightest in September and October. (See a long paper by Barnard, in the *English Mechanic*, March 21, 1919). It also is probably due to sunlight reflected from meteoric bodies.

Occultations take place when the Moon or a planet passes in front of some celestial body, shuttting it out from view. The Moon frequently occults stars; the disappearance, or *immersion*, is always on the E. side of the Moon, the reappearance, or *emersion*, on the W. side: sometimes (but rarely) the Moon occults a planet. When the star is bright, the instantaneous disappearance and re-appearance are almost startling: very rarely, the star seems to hang for an instant on the limb, perhaps chancing on some irregularity parallel to the Moon's motion. Duration, see next page.

The Moon's (star) shadow is 2160 miles in diameter on the fundamental plane (p. 3), and has no penumbra; it sweeps across the Earth from W. to E., in the direction of the Earth's rotation, which makes occultations last longer than they would with a non-rotating Earth. The *N.A.* occultation list gives the parallels of latitude within which they are seen: near these limits, the small breadth of the shadow (oval, in general) confines visibility to a very limited district.

Eclipses occur when (*a*) the Moon passes in front of the Sun†; (*b*) a satellite enters its primary's *shadow* (the *body* blots out, in occultations), and becomes invisible, though nothing intervenes, because the Sun no longer illumines it.

In *Solar Eclipses*—which, strictly speaking, are really occultations of the Sun—the eclipse begins on the west side of the Sun's disc, and the shadow sweeps across the Earth's surface from west to east; in *Lunar Eclipses*, the eclipse begins on the east side of the disc, and sweeps over it westwards. The *umbra*, or *shadow*, is the dark shadow on that portion of the Earth in solar, of the Moon in lunar eclipses, which, for the time being, receives no direct light from the Sun. The umbra shades away into the bordering *penumbra* or partial shadow, which covers those regions of the Earth or Moon whence the Sun would be seen partially eclipsed: the edge between them is never sharply defined.

First Contact occurs, in a solar eclipse, at the instant when the discs of the Sun and Moon first appear to touch, *i.e.*, when the eclipse begins: *Last Contact* at the instant of the end of the eclipse. In the case of a lunar eclipse, we have two First Contacts—at the instant when (1) the penumbra, and (2) the umbra or shadow, first touch the Moon's disc; and similarly two Last Contacts, at the moment when (3) the shadow, and (4) the penumbra respectively leave the disc.

The *magnitude*, or extent, of partial and annular eclipses is indicated by expressing the proportion of the diameter eclipsed as a decimal of the full diameter, at the time, of the Sun's or Moon's disc; in solar eclipses it varies according to the locality, but in lunar eclipses it is the same at any place from which it is visible.

In a total lunar eclipse, the magnitude is indicated as the ratio to the Moon's diameter at the time taken as 1; any eclipse less than 1 will be a partial one, while the maximum will be about 1·8, but this only occurs when the Moon is simultaneously in perigee and on the Ecliptic. The further the Moon is from the Ecliptic, the shorter is the duration of totality, and the nearer the points of first and last contact to the lunar poles.

Lunar Eclipses, when total and central, may last as long as 3 hours 48 minutes from first to last contact of the umbra, or up to 6 hours including the penumbral stage; the maximum duration of totality is 1 hour 42 minutes. Usually the Moon does not altogether disappear from view, even at mid-eclipse, but shines with a dull reddish-orange or greyish light, being illuminated by sunlight refracted by the Earth's atmosphere: the colour and brightness depend on the amount of water vapour and clouds present in the Earth's atmosphere at the time. On rare occasions the clouds intercept all or nearly all the rays that would be refracted, so that the Moon becomes nearly or altogether invisible.

Solar Eclipses, both total and annular, are rarely visible from any given place, the 'expectation' being only one in 360 years. Some 3 or 4 hours elapse between first and last contact, but totality never exceeds 7 m. 40 secs., and annularity 12½ minutes: both are usually much less. At the equator, both totality and contact-interval last about a quarter longer than at lat. 50°. The width of the zone of totality averages less than 100 miles, but where the Sun is in the zenith it may be about 167 miles.* Partial solar eclipses are of little interest, the Sun merely appearing notched; the temperature may fall perceptibly, however, and about mag. ·97, Mercury, Venus, and stars may appear.

Transits of Mercury and Venus.—Transits of *Venus* happen twice at the short interval of eight years, and then do not recur for over 100 years (105½ and 121½ alternately). Last transits, 1874, 1882; next transits, 2004, 2012.

Mercury transits the Sun about four times in 33 years, and *at the same node* at intervals of 7, 13, 33 or 46 years. The transits always happen at the descending node in May, or at the ascending node in November. Transits take place in May [1924], 1957, and 1970, and in November [1927], 1940, 1953, 1960 and 1973. (See Note on Transits, p. 42).

*See Track Charts in the *N.A.* † Or, in binaries, one star passes before the other.

Duration of Occultations.—The Moon's mean daily motion among the stars is 13°·18, or 0°·55 per hour, as seen from the Earth's centre. The Moon's mean angular diameter being 0·518°, for a central occultation her (star) shadow takes nearly an hour, on the average, to pass the Earth's centre, and still longer a point on the Earth's surface, where by her rotation, an observer is being carried in the same general direction as the shadow is travelling. At the Earth's equator the speed is about 1030 miles, and at latitudes 45° and 52°, 734 miles and 640 miles per hour, respectively: the duration of an occultation, therefore, shortens with increasing latitude, but in finding the actual duration, the Moon's varying velocity and angular diameter, and other factors, have to be taken into account. The track of the centre of the shadow may take strange curves, very similar to those of the tracks of various solar eclipses given in the *N.A.* In the latitude of Greenwich, some central occultations may last about $1\frac{1}{2}$ hours.

Occultation Period.—Owing to the westward motion of the Moon's node along the Ecliptic (about $1\frac{1}{2}°$ per nodical month), the Moon's monthly path among the stars is always changing, circling the star sphere back to the same node in 18·59 years. *On the average*, therefore, each star within about $6\frac{1}{4}°$ of the Ecliptic has the chance of being occulted twice during that interval, when it is passed successively by the ascending and descending quadrants of the Moon's path. These 'passings' are at average intervals of $9\frac{1}{4}$ years for stars on the Ecliptic itself; for other occultable stars the interval between the passings shortens as the distance from the Ecliptic increases (with a correspondingly longer interval to the next pair), till, at the occultable limit, the two passings coincide. But the intervals are not constant, owing to the varying inclination of the Moon's orbit, the node's irregular and sometimes (as regards the mean) reversed motion, &c., so that an occultation *may* be repeated during many months—or even some years, for stars near the occultable limit, where the monthly paths are closely crowded—before the path finally departs from the star.

Twilight, from ancient times, has been reckoned as ending when the Sun's centre is 18° below the horizon, 6th magnitude stars then being visible in the zenith; it has no definite duration, however, as meteorological conditions may modify it. The glow, in its later stages is a segment of a circle, brightest vertically over the Sun. Directly opposite, the indigo-blue segment of the unilluminated atmosphere rises from the east as the Sun recedes from the horizon.

Twilight lengthens with distance from the Equator, and is shortest all over the Earth about the Equinoxes. The total variation never exceeds half an hour below latitude 40°, and in higher latitudes, some 10-20 minutes during autumn, spring, and winter; but above lat. 40°, in summer twilight lengthens, till it lasts all night above 50°. *Civil*, *Nautical*, and *Astronomical Twilight* (British *N.A.*) end when the Sun's centre is 6°, 12°, and 18° below the horizon—the first about the limit when "ordinary outdoor operations become impracticable without artificial light." Table p. xiv.

Twinkling of Stars.—Though purely atmospheric in its origin, this phenomenon is of interest to astronomers, as it is affected by the nature of the light emitted by each star, *i.e.*, by its spectrum. White stars (Types B and A) twinkle most; yellow stars (Types F to K) slightly less, and red stars (Type M) least of all. Twinkling is least at the zenith, and in settled and calm weather; and greatest toward the horizon, and in unsettled and stormy weather: there is also a seasonal waxing and waning from mid-summer to mid-winter and *vice versa*. Planets do not usually twinkle except when near the horizon—supposed to be due to the fact that they have discs of an appreciable size.

The Green Flash, or 'Green Ray,' occasionally seen for a second or two before the instant of sunset or sunrise, is a beautiful solar phenomenon, due, like twinkling, to atmospheric causes; it is more often visible if an opera-glass is used. The general conditions required are a distant, sharply-defined, and low (preferably sea) horizon: avoid looking at the Sun till the last moment. Cool weather and absence of red tints seem to favour visibility. Sometimes it takes the form of a *white* flash followed by a deep blue one. While the duration is usually only a second or two, it tends to lengthen with increase in latitude, especially if the horizon is nearly parallel to the Sun's motion. In the Antarctic, it has been observed for 30 minutes. *A Red Flash* is sometimes seen as the Sun's *lower* edge emerges from a dark cloud near the horizon: it may last minutes if the cloud's motion is nearly the same as the Sun's.

Auroræ are believed to originate in the Sun. There is general agreement between the sunspot maximum and minimum and their greatest and least frequency, and though no definite relationship with sunspots has yet been demonstrated, magnetic storms and auroræ frequently occur when large spots are on or near the Sun's central meridian: they may be due to rays shot out from certain areas of the Sun's surface—not necessarily radially, or from where a sunspot is seen. Auroræ appear in various forms: diffuse areas, arcs, rays, beams, curtains, patches, &c. (details see p. 44). The ordinary height is some 87 to 300 kilometres (55-180 miles), but altitudes of 1000 km. (620m.) have been recorded.

Auroræ are most frequent about the time of the equinoxes—especially just after.* In Europe, some thirty may be seen annually on the line Inverness-Oslo; south of that line the number rapidly falls off, and south of the latitude of Paris, they appear only at long intervals. In America the corresponding limits are Quebec-Alaska, and Washington.

The colour of Auroræ is ordinarily faint white, silvery or delicate green in the brighter parts; red may appear, especially in the diffused type, or towards the lower edge of other types, and may pass into yellow-green. The auroral spectrum (also that of the night sky, faintly), has a characteristic green line—λ5577—due to oxygen and nitrogen.

Luminous phenomena, simulating auroral forms, also occur (rarely) near or even at ground level, and owing to undoubted theoretical difficulties (in our present state of knowledge) are usually attributed to mist or optical illusion. These explanations, however, do not account for the apparent absence of reports of such illusions from the regions of lesser auroral activity, where they are equally likely to occur, nor do they satisfy an actual witness of a 'low aurora.'

* See 'Auroræ,' Encyclo. Brittannica., 11th edition.

VI. HINTS ON OBSERVING, &c.

Atmospheric Conditions.—To get the best results, objects should be viewed when they are as far as possible above the horizon, *i.e.*, when near culmination. Satisfactory observations cannot be made of objects at low altitudes, owing to the increased intervening thickness of the atmosphere, and the haze and mist which so often obscure the horizon. The nights when the sky is darkest, and the stars most brilliant, are not always the best for observations. Faint and ill-defined objects, such as some nebulæ, may, however, often be seen to advantage on such nights.

During a slight haze, the air is often very steady, and splendid views of bright objects may then be obtained. If the stars twinkle much, it indicates that the air is unsteady and not altogether satisfactory for observation.

Viewing Faint Objects.—The eye becomes much more sensitive to faint impressions after it has been kept in the dark for a considerable time. A slight change of focus is often restful to the tired eye.

Very faint objects, otherwise invisible, may sometimes be detected by averted vision: the eye is directed to another part of the field, while the attention is fixed on the spot where the object is supposed to be.

Making Notes: Consulting Charts, &c.—A bull's-eye lantern with a slide to shut off the light is of great use. A cycle lamp may be utilised by the occasional observer. A photographic red lamp is even better, as it does not affect the sensitiveness of the eye. It may be placed on a support at some distance from the observer, and so directed as to throw a *faint* light on the book or card, when notes or sketches are being made at the telescope. A strong light should be avoided, as it makes the eye less sensitive for observation.

A small table to hold the maps and other books, with a lantern having a shade to throw the light downwards, lest the direct rays of light should reach the eye, is almost a necessity; a special shelf may be fixed up in an out-house.

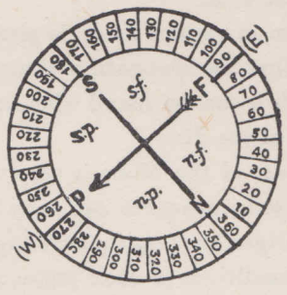
All observations should be written down at the time, when they are made. The notes should be clearly worded, and should have entered on them the year, month, day, hour, and minute of the observation, together with the aperture and power of the telescope, and the state of the air. In Earthshine observations, the temperature, barometer reading, and direction of the wind should also be noted, as meteorological conditions have some influence on the brightness.

Direction in an Inverting Telescope.—In the inverted view of an object, as seen in astronomical telescopes (except 'Gregorians'), to observers in the Northern Hemisphere the upper part of the field of view is south, while the lower part is north; east is on the right hand of the object, and west on its left side.

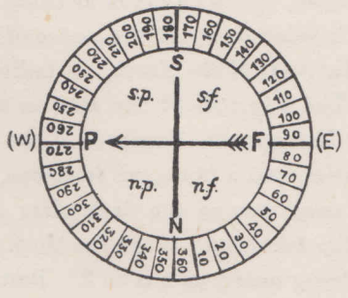
To observers south of the Equator the reverse is the case; the upper part of the field is north, and the lower south; east is on the left hand of the object: west, on its right.

For circumpolar stars, however (*i.e.* those a less number of degrees from the Pole than the observer), the rule does not hold, as the observer is facing the other way, and objects on opposite sides of the Pole are moving in opposite directions.

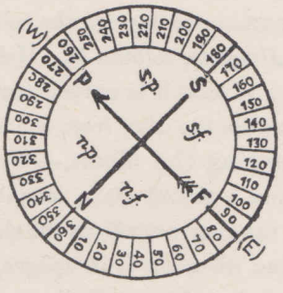
North Preceding, &c.—To get over these difficulties in describing how to find a celestial object in the field of view, the phrases 'North (or South) preceding,' 'North (or South) following,' a certain star, are commonly used. *North* (or *South*) indicates that the object is nearer the North (or South) celestial pole than the star referred to; *Preceding* that its Right Ascension is *less* than that of the reference star, and *Following*, that its R.A. is *greater*, thus indicating the



Between rising and culmination.
(*Angle depending on latitude of observer and declination of star*).



Southing or culminating.
(*Upright*).



Between culmination and setting.
(*Angle depending on latitude of observer and declination of star*).

n.p.=North preceding. *n.f.*=North following. *s.p.*=South preceding. *s.f.*=South following. *P*=West. *F*=East.

direction in which to find the required object. The annexed diagram indicates how the hour-circle—which coincides with the line SN in the diagram—lies with respect to the horizon in an inverting telescope, when in different positions, and how a Position angle (P.A.) will in consequence occupy varying positions in the field of view.

In the diagram, the arrow denotes the apparent path of a star with reference to the horizon, as it crosses the field of view of a fixed inverting telescope in the N. Hemisphere. This path will be horizontal only when the object is on the meridian, but the relative positions remain unchanged. In the S. Hemisphere, hold the book upside down.

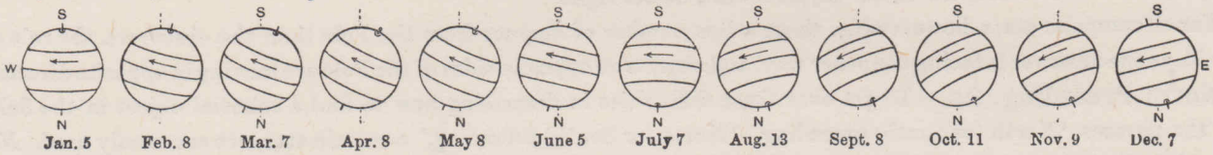
Observing the Sun.—It is extremely dangerous to attempt to view the Sun unless proper precautions are taken: blindness may be the penalty of rashness or ignorance. A perfectly safe method is to support a smooth, white card, at the distance of about a foot from the eye-piece, and to focus the image of the Sun projected on it. The screen should be held in a covered frame-work or box, and the picture of the Sun viewed through a hole in one of the sides. If, on the other hand, the Sun is viewed directly through a dark-glass cap, a larger aperture than 2 inches cannot safely be used in the heat of summer. A stop made of a card, with a circular hole of 2 inches or less in diameter, should be fitted over the object glass of a larger instrument, to reduce the amount of light and heat transmitted: this, however, tends to reduce the sharpness of the definition. A special solar eye-piece can be obtained which enables full apertures to be used with safety.

Observing Prominences, by the spectroscope. The edge of the Sun's image should be made to fall on the nearly-closed slit of the spectroscope—which must be one of considerable dispersive power. The telescope should then be driven (preferably by clockwork) so as to keep the image in the same position. The spectroscope is next focussed on one of the hydrogen lines of the spectrum, and, on the slit being opened, the prominence will be seen. Good views may be obtained in this way, using a 3-inch telescope with a spectroscope having several prisms.

Observing Sunspots.—In studying their motion across the disc from east to west (see note, p. 39, as to direction in inverting telescopes), the position angle (p. 5) of the Sun's axis requires to be taken into consideration, as the apparent path varies according to the time of the year. The spots only move in straight lines across the disc about June 5 and December 7, on which dates alone the solar equator is seen as a straight line on the disc, dividing it into two hemispheres, with the poles exactly on the limb. At all other times, one pole alone is visible—very near the limb owing to foreshortening—and the solar equator lies on one side or other of the apparent centre of the disc, and is curved downwards or upwards, as are also the paths of the spots: maximum curvature northwards, about March 7; southwards, about Sept. 8. Sunspots take about a fortnight to traverse the disc from limb to limb,* and will reappear after the same interval if they survive. Naked-eye spots have a diameter not less than about 1/60th of the disc (31″).

The variation of the position angle of the Sun's axis during the year (for the *North* pole) is about as follows:—

Jan. 5,	July 7,	0°	Feb. 23,	May 19,	20° W.	July 7,	Jan. 5,	0°	Aug. 28,	Nov. 20,	20° E.
,, 16,	June 26,	5° W.	Mar. 7,	May 8,	23° W.	,, 19,	Dec. 26,	5° E.	Sept. 8,	Nov. 9,	23° E.
,, 27,	,, 15,	10° W.	,, 18,	Apr. 26,	25° W.	,, 30,	,, 16,	10° E.	,, 21,	Oct. 30,	25° E.
Feb. 8,	June 5,	14° W.	April 8,	...	26°42′W.	Aug. 13,	Dec. 7,	14° E.	Oct. 11,	...	26°42′E.



The distance of the Sun's visible pole from the limb has necessarily been exaggerated in the diagram. **N, S,** indicate the line of the hour circle, N showing North in an inverting telescope—nearest the horizon in the N. Hemisphere. In the S. Hemisphere, hold the book upside down.

Near the times of the greatest inclination of the axis to the hour-circle, spots just appearing on the limb in the high spot-latitude of 45°, are, by the inexperienced, apt to be taken as being near the poles.

The number of degrees the solar equator is below or above the centre of the disc on various dates, is given in the *Nautical Almanac*, column B_0, 'Heliographic Latitude of the Earth,' + indicating that the spot-path is curved southwards, and − that it is curved northwards. The longitude of the spot on the surface can be found when it arrives half-way across the disc, from the column L_0, 'Heliographic longitude of the centre of the disc.'

Observing the Moon.—With a low power, and a fair-sized telescope, the glare of the Moon is very trying to the eye, and a tinted glass, mounted in the same way as the dark glass of the solar eye-piece cap, may be used. Reducing the aperture affects the sharpness of the definition. When the Moon is in perigee, the brightness is appreciably greater than when she is in apogee, the ratio being nearly as 4 is to 3. Best-seen conditions of each phase, see p. 29.

Observing Lunar Eclipses.—Mid-winter eclipses have the best altitude conditions, mid-summer ones the least favourable, for the reason given p. 29. First contact is always on the E. side of the disc, and through the telescope the Earth's shadow may be seen sweeping slowly across it, but the edge is not sharply defined. It should be noticed that from first to last, the 'preceding' edge of the umbra is always uniformly convex, unlike the dark terminator of the young Moon, which, though convex at first, daily grows less convex, till, at First Quarter, it is straight, and finally becomes increasingly concave. Similarly, the 'following' edge of the umbra is also always convex. Phenomena that may be noted are the visibility or otherwise of the rays, and of prominent craters, &c., such as Aristarchus and Copernicus: also the variations of colour as the eclipse progresses, on different parts of the disc.

* Stonyhurst discs, for measuring the positions of sunspots and faculæ by projection, can be obtained from Messrs Casella & Co., Scientific Instrument makers, London. For the method of using them see 'Memoirs of the Brit. Astr. Assn., Vol. XXIII., Part II.

Observing the Superior Planets.—In temperate latitudes, summer observations of these planets are always conducted under unfavourable conditions as to altitude; in winter, the altitude conditions are the most favourable. This results from the planets being always near the Ecliptic, so that their highest altitude above the observer's horizon at culmination is much the same as that of the Ecliptic where it cuts his meridian. At mid-summer, midnight culmination is at its lowest, and in mid-winter at its highest. Thus observers in the Northern hemisphere, outside the tropics, are better situated for observing the oppositions between October and March, than those in the Southern hemisphere, while observers in the latter are better placed for seeing oppositions between April and September.

A curious effect of the two-year synodic period of Mars is, that for some eighteen months or so in succession, he is visible at some time or other every night, then becomes lost in twilight and daylight for some four or six months.

The angular diameter, or semi-diameter, of a planet's disc on any date, will be found in almanacs: the diagram indicates, on a uniform scale, the range of changes, and relative sizes, of the discs, and the favourableness, or otherwise, of the size of the disc can easily be inferred by reference to the mean diameter.

Saturn. Min. 15″ Mean. 18″ Max. 21″. **Uranus.** 3½″. **Mars.** Min. 3½″ Mean. 15″ Mean. opp. 19″ Max. 25″. **Jupiter.** Min. 30″ Mean. 40″ Max. 50″.

Observing Mercury and Venus.—The most favourable seasons of the year are indicated on page 33. For Mercury, Southern observers have the best conditions, as his maximum elongation occurs when he is in S. Declination.

Observing Occultations.—Beginners will probably be rather puzzled to know the direction in which the Moon will approach the star, owing to the varying position of the Moon's axis with respect to the horizon: the direction, however, is approximately at right angles to the line joining the cusps, or horns of the Moon.

The Moon's mean hourly motion being fully ½°, the rate of approach is about a quarter of the Moon's diameter in 14 minutes, or the apparent diameter of Hipparchus in about 2¾ minutes, or of Copernicus in about 1½ minutes. The time, however, is modified by the latitude of the observer, &c.

Observing the Zodiacal Light.—As the axis of the Light approximately coincides with the Ecliptic, the most favourable conditions in temperate latitudes are when the Ecliptic is most nearly vertical to the horizon soon after sunset, or before sunrise, which in the evening is before the Spring equinox, and in the morning after the Autumnal equinox, of each hemisphere. The nearest approach to verticality is always when 6 hrs. R.A. is on the meridian (N. Hemisphere), or 18 hrs., (S. Hemisphere); at that instant, too, both the direction of the lowest portion of the Light, also the verticality, are most easily found, as the Ecliptic then intersects the horizon exactly due west and due east,* and its angle with the horizon is equal to the co-latitude of the observer *plus* 23½°.

The Zodiacal Light proper cannot be longer above the horizon than six hours after sunset, or before sunrise, as its extension from the Sun is reckoned as about 90°, but of course it will only be distinguishable for a much shorter period, twilight preventing observation for perhaps an hour after sunset, in the higher temperate latitudes; and the haze of the horizon obscuring its faint extremity for long before setting. For brightness, compare with Milky Way.

The Table below gives the approximate dates and hours when the Ecliptic is most nearly vertical during the short observing season. The dates at the top are for the N. Hemisphere; those at the foot (in italic) for the S. Hemisphere. The position of the foot of the Light on the horizon for three or four hours after (or before) the hours mentioned is easily found, as its movement in azimuth westwards, may be taken as about 6° per hour, over that period; similarly, the decrease per hour in inclination after (or before) greatest verticality is, roughly, 2°.

Feb. 5	Feb.12	Feb.20	Feb.27	Mar.7	Mar.14	Mar.22	Sept.22	Sept.29	Oct.7	Oct.14	Oct.22	Oct.30	Nov.7
9 p.m.	8·30	8 p.m.	7·30	7 p.m.	6·30	6 p.m.	6 a.m.	5·30	5 a.m.	4·30	4 a.m.	3·30	3 a.m.
Aug. 6	*Aug.13*	*Aug.21*	*Aug.29*	*Sept.6*	*Sept.13*	*Sept.21*	*Mar.23*	*Mar.31*	*Apr.8*	*Apr.15*	*Apr.23*	*Apr.30*	*May 8*

Observing the Milky Way.—The Milky Way circles round the Celestial poles once each sidereal day, its central line passing within 27° of the N. pole, in the W of Cassiopeia, and within 27° of the S. pole, near α Crucis.

In the N. hemisphere, in the latitude of Britain and the U.S.A., it passes through or near the zenith during the hours when R.A. 22 hrs. to 4 hrs. are on the meridian; thereafter it approaches the horizon, till, when R.A. 13 hrs. is on the meridian—and for some time before and after—it lies so close along the N. horizon for most of its visible length that it is hardly observable, after which its altitude begins to increase again. The Cassiopeia-Argo section is visible to its maximum extent when R.A. 8 hrs. is on the meridian, and the Cassiopeia-Scorpius section when R.A. 16h. is on the meridian, but the portions near the horizon are not well seen. For favourable observing times, consult Table p. xiv.

In the S. hemisphere, in the latitude of Cape Colony and Southern Australia, the corresponding phases are:—overhead, R.A. 10hrs. to 16hrs. on the meridian; on the horizon, R.A. 1hr. on the meridian. The Crux-Cygnus and Crux-Perseus sections are visible to their maximum extent when R.A. 20hrs. and R.A. 4hrs., respectively, are on the meridian.

* The compass-direction requires correction for the magnetic variation; see 1-inch Government Maps.

Observing Variable Stars.—The 'variable' is compared with neighbouring stars of similar brightness and of known magnitude. Two comparison stars are found, one rather brighter than the variable, the other slightly fainter; the magnitude of the variable will be between those of the comparison stars, and the nearer their magnitudes, the more accurate the result. Except for rough estimates, a catalogue of magnitudes is required, or a special star chart, such as those for Novæ and interesting variables given from time to time in the British Astron. Association Journal, or 'sequences,' *i.e.*, lists of standard stars, arranged in order of magnitude for this purpose.

The dates of maxima and minima are recorded by the Julian Day (J.D.)*—which begins at *noon*, not midnight, (p. 9)—and decimals of a day, but observations cannot always be made, as the date may fall when the star is near the Sun, or during moonlight. The annual B.A.A. Handbook gives useful observing information, dates of maxima, &c.

It is important, where possible, (*a*) to observe the star when at its highest altitude; (*b*) that the comparison stars be about the same altitude, so that atmospheric absorption (see below) will equally affect their magnitudes; (*c*) that they be as nearly as possible similar in colour to the variable, as it is very difficult to estimate correctly the real relative brightness of two stars differing widely in colour, as, for instance, in the case of Betelgeuse and Rigel. For a curious optical phenomenon—known as the *Purkinje Effect*—comes into play, namely, that if red and green lights, appearing equally bright, are increased or decreased in the same ratio, in neither case will they now appear of equal brightness; the red will seem the brighter when the light is increased, but the green when the light is decreased.

Estimating Magnitudes: Atmospheric Absorption.—For accurate valuation of the magnitudes of bright variable stars, if the comparison stars are not about the same altitude, allowance must be made for the difference, as atmospheric absorption diminishes the brightness (apart from haze) by approximately the following magnitudes:—

Zenith distance.	47°	58°	64°	69°	71°	73°	75°	77°	79°	80°	84°	86°	88°	89°
No. of mags. diminished.	$\frac{1}{10}$th	$\frac{2}{10}$ths	$\frac{3}{10}$ths	$\frac{4}{10}$ths	$\frac{5}{10}$ths	$\frac{6}{10}$ths	$\frac{7}{10}$ths	$\frac{8}{10}$ths	$\frac{9}{10}$ths	1 mag.	$1\frac{1}{2}$m.	2m.	$2\frac{1}{2}$m.	3m.
Altitude above horizon.	43°	32°	26°	21°	19°	17°	15°	13°	11°	10°	6°	4°	2°	1°

Comet Seeking.—In searching for comets, a telescope of fairly large aperture and of short focal length, with an eye-piece of low power having a large field of view, should be used. The observer should slowly 'sweep' (*i.e.*, move the telescope in a horizontal direction) for some distance, a careful watch being kept all the time. At the end of the sweep the telescope is *slightly* raised or lowered, and an overlapping sweep is taken in the opposite direction. This process is repeated continuously. Should a nebulous-looking object be noticed, the comet-hunter must look in his catalogue of nebulæ to see if the object can be identified. If not, he should draw a careful sketch of its position among the neighbouring stars. If in the course of time any movement can be detected, and the place of the suspected object does not agree with that of any known comet, its position should be determined as accurately as means will allow, and a telegram giving particulars should be sent to Greenwich (or the corresponding) Observatory.

Observing Transits.—There are four contacts: *external contact*, at ingress and egress, *i.e.*, entering or leaving the Sun's or planet's limb; and *internal*, when entering completely on or beginning to depart from, the disc.

The Black Drop, seen at internal contact when Venus (sometimes Mercury) is just touching the Sun's limb, is a curious drawing-out of the planet's black disc to the Sun's limb, in a broad band or ligature, which gives it the appearance of a drop of black ink hanging internally from the Sun's limb. In a few seconds the band contracts, then breaks: this renders the instant of internal contact uncertain. A very narrow brilliant circle of light is sometimes seen surrounding Venus near first and last contacts; it is probably due to sunlight refracted by her atmosphere.

Observing Nebulæ.—These faint objects lose least light by atmospheric absorption when near the zenith, hence those showing a preference for the Galactic plane are most favourably situated when the Milky Way is nearly overhead, but those showing a preference for the Galactic poles, when the Milky Way lies near the horizon. Suitable times for observation can be found by the notes on p. 11, along with the Table of Sidereal Time on p. xiv.

Observing Earthshine.—The degree of visibility of the outlines of the Maria, and of Aristarchus, Copernicus, and other prominent craters, affords a good index of the state of the atmosphere. The thermometer and barometer readings, and direction of the wind should be noted, as meteorological conditions have some influence on the brightness.

Observing Novæ.—The following changes generally occur in the spectra and colour; there may be considerable variations from the normal, some stages missing, and individual peculiarities. I. A. U. Notation (1922, 1928) below.

1. Continuous spectrum: ... ... White
2. Hydrogen lines double: bright & dark lines: „
3. Lines widen: continuous spectrum fades.
4. Nebula lines appear: ... ... Yellow
5. Hydrogen lines brighten up: Red
6. Hydrogen lines fade: ... Orange
7. Nebula lines more prominent than hydrogen ones, ... Bluish
8. Star now a planetary nebula.
9. Nebula lines fade: spectrum now faintly continuous, bright Wolf-Rayet bands.

Qa; absorption lines and bright bands (faint). **Qb**; stronger absorp. lines (mainly enhanced metallic, many double) and bright bands. **Qc**; absorption metallic lines of *O*, *N*, *He*, enhanced metallic lines predominating. **Qd**; as Qc, but gaseous lines predominating. **Qu**; broad nebulous emission bands near λλ3480, 4515, 4640. **Qx**; bright bands (enhanced *O*, *N*, *He*); absorption lines faint. **Qy**; as Qx, bright nebular bands. **Qz**; bright nebular and weak Wolf-Rayet bands. **Qz-O5**; as Qz, Wolf-Rayet bands strong.

Combination spectra indicated by combining the small letters, placing the most prominent first.

* Sometimes J.A.D.—Julian Astronomical Day.

Observing Meteors.—Showers from radiants within or near the circle of the 'always-seen' stars of any locality are observable all night, more or less, but the observing interval shortens as the distance from that circle increases, until, for the more remote, should the culmination-hour be many hours after midnight, the shower is never observable from that latitude except for a few hours before sunrise. Thus the November Leonid shower is only a morning one as the radiant culminates about 6 a.m., and only rises about midnight. Some meteors from a radiant just below the horizon *may* be visible, however. The possible observing-hours can be found from the star Table on page xiv.

The following are the important points to note:—Date; Greenwich Mean Time (G.M.T., U.T.) of appearance; R.A. and Dec. of beginning and end of flight, and duration in seconds; colour and stellar magnitude, stating comparison star; path, if straight or wavy; streak or train, if any, and the colour, duration, direction and speed of drift; any other notes. A *streak* is the faint, phosphorescent narrow band, sometimes coloured, which endures for a time along the path of some meteors: a *train*, a spark-like and usually quickly-disappearing appendage. The R.A. should be stated in degrees (see conversion Table below), and the observation communicated to the Director, Meteor Section of the British Astronomical Association, London, or to the American Meteor Society. Cambridge, Mass.

For counting seconds, the well-known photographic rule 'One, two, three, ONE; one, two, three, TWO; &c.', pronounced rapidly but distinctly, gives very near results.

List* of Important Showers.—The Radiant position may change a degree or two on successive days, and a look-out should be kept before and after the dates given, as leap year adjustments cause small variations. For a Radiant on every night of the year, see B.A.A. Handbook, 1922; and list of 1000 radiants, *Mem. R.A.S.*, vol. 53.

The column headed 'Cul.' gives the Radiant's approximate hour of culmination on the central date, 'a' denoting a.m.; 'p' p.m.

Date.	Shower.	Cul.	Radiant. R.A. = h. m.	Dec.	Speed, &c.
Jan. 2-3	**Quadrantids**	9a	230° = 15 20	53° N	Medium.
„ 17	κ Cygnids	12a	295° 19 40	53° N	slow, trained.
Feb. 5-10	α Aurigids	8p	75° 5 0	41° N	v. sl., fireballs.
Mar. 10-12	ζ Boötids	3a	218° 14 32	12° N	swift, streaks.
Apl. 20-22	**Lyrids**	4a	271° 18 4	33° N	do
May 6	γ **Aquarids**	7a	334° 22 16	2° S	v. swift[3].
„ 11-24	ζ Herculids	1a	247° 16 28	28° N	swift, white.
„ 30	η Pegasids	6a	333° 22 12	27° N	v. sw., streaks
June 2-17	α Scorpiids	12p	253° 16 52	22° S	v. sl., fireballs.
„ 27-30	ι Draconids	9p	228° 15 12	57° N	v. slow[4].
„ -Sept	γ do	9p	269° 17 56	48° N	slow, trained.
July 18-30	α Cap'cornids	12p	304° 20 12	12 S	v. sl., bright[5].
„ -Aug	α Cygnids	12p	315° 21 0	48 N	sw., last long.
„ 25-Au. 4	α-β Perseids	7a	48° 3 12	43 N	v. sw., streaks
„ 25-30	δ Aquarids	2a	339° = 22 36	11 S	sl., long paths.

Date.	Shower.	Cul.	Radiant. R.A. = h. m.	Dec.	Speed. &c.
Aug. 10-12	**Perseids**[1]	6a	45° = 3 0	57° N	v. swift.
„ 12-Oct. 2	α Aurigids	6a	74° 4 56	42° N	v. swift, streaks.
Aug.-Sept.	Lacertids	12p	332° 22 8	49° N	medium, short.
„ 10-20	κ Cygnids	10p	290° 19 20	54° N	„ bright.
„ 21-23	o Draconids	9p	291° 19 24	60° N	v. slow: max. 1879.
„ 21-31	ζ „	7p	263° 17 32	62° N	slowish, bright.
Sept. 7-15	ε Perseids	5a	61° 4 4	35° N	swift, streaks.
Oct. 2	Quadrantids	3p	230° 15 20	52° N	slow. In 1877.
„ 12-23	ε Arietids	1a	42° 2 48	21° N	v. slow, fireballs.
„ 18-20	**Orionids**	4a	92° 6 8	15° N	swift, streaks.
„ 30-Nv. 17	ε Taurids	1a	64° 4 16	22° N	slow, fireballs.
Nov. 3-15	e „	12p	55° 3 40	13° N	v. slow, bright.
„ 13-15	**Leonids**[2]	6a	150° 10 0	22° N	v. swift: period
„ 17-27	**Andromedids**	10p	25° 1 40	43° N	v. slow[6]. [33⅓yrs
Dec. 10-12	**Geminids**	2a	112° = 7 28	33° N	med'm, white, rich

Notes. [1] The Perseids are visible during July and Aug. (a rich display, max. Aug. 10-12): the radiant moves from about 2° +41° to 68° +61° (Androm. to Camelop.). [2] The Leonids, or November meteors, are seen at their best about every 33 years: plentiful in 1799, 1833, and 1866, but the 1900 display was not brilliant owing to the disturbance of their orbit by Jupiter.
[3] Long paths, before sunrise; Halley's comet. [4] Pons-Winnecke's comet. [5] Comet 1881 V. [6] Biela's comet.

R.A. Hours & Minutes converted into Degrees, or vice versa; 1 min. = ¼°. (Reads continuously *across* page).

hrs.	0m.	4m.	8m.	10m.	12m.	15m.	16m.	20m.	24m.	28m.	R.A.	30m.	32m.	36m.	40m.	44m.	45m.	48m.	50m.	52m.	56m.	hrs.
0	...	1°	2°	2½°	3°	3¾°	4°	5°	6°	7°	0h.	7½°	8°	9°	10°	11°	11¼°	12°	12½°	13°	14°	0
1	15°	16	17	17½	18	18¾	19	20	21	22	1	22½	23	24	25	26	26¼	27	27½	28	29	1
2	30	31	32	32½	33	33¾	34	35	36	37	2	37½	38	39	40	41	41¼	42	42½	43	44	2
3	45	46	47	47½	48	48¾	49	50	51	52	3	52½	53	54	55	56	56¼	57	57½	58	59	3
4	60	61	62	62½	63	63¾	64	65	66	67	4	67½	68	69	70	71	71¼	72	72½	73	74	4
5	75	76	77	77½	78	78¾	79	80	81	82	5	82½	83	84	85	86	86¼	87	87½	88	89	5
6	90	91	92	92½	93	93¾	94	95	96	97	6	97½	98	99	100	101	101¼	102	102½	103	104	6
7	105	106	107	107½	108	108¾	109	110	111	112	7	112½	113	114	115	116	116¼	117	117½	118	119	7
8	120	121	122	122½	123	123¾	124	125	126	127	8	127½	128	129	130	131	131¼	132	132½	133	134	8
9	135	136	137	137½	138	138¾	139	140	141	142	9	142½	143	144	145	146	146¼	147	147½	148	149	9
10	150	151	152	152½	153	153¾	154	155	156	157	10	157½	158	159	160	161	161¼	162	162½	163	164	10
11	165	166	167	167½	168	168¾	169	170	171	172	11	172½	173	174	175	176	176¼	177	177½	178	179	11
12	180	181	182	182½	183	183¾	184	185	186	187	12	187½	188	189	190	191	191¼	192	192½	193	194	12
13	195	196	197	197½	198	198¾	199	200	201	202	13	202½	203	204	205	206	206¼	207	207½	208	209	13
14	210	211	212	212½	213	213¾	214	215	216	217	14	217½	218	219	220	221	221¼	222	222½	223	224	14
15	225	226	227	227½	228	228¾	229	230	231	232	15	232½	233	234	235	236	236¼	237	237½	238	239	15
16	240	241	242	242½	243	243¾	244	245	246	247	16	247½	248	249	250	251	251¼	252	252½	253	254	16
17	255	256	257	257½	258	258¾	259	260	261	262	17	262½	263	264	265	266	266¼	267	267½	268	269	17
18	270	271	272	272½	273	273¾	274	275	276	277	18	277½	278	279	280	281	281¼	282	282½	283	284	18
19	285	286	287	287½	288	288¾	289	290	291	292	19	292½	293	294	295	296	296¼	297	297½	298	299	19
20	300	301	302	302½	303	303¾	304	305	306	307	20	307½	308	309	310	311	311¼	312	312½	313	314	20
21	315	316	317	317½	318	318¾	319	320	321	322	21	322½	323	324	325	326	326¼	327	327½	328	329	21
22	330	331	332	332½	333	333¾	334	335	336	337	22	337½	338	339	340	341	341¼	342	342½	343	344	22
23	345	346	347	347½	348	348¾	349	350	351	352	23	352½	353	354	355	356	356¼	357	357½	358	359	23

* List of S. Hemisphere Radiants, see *M.N.*, vol. 95, p. 709, 1935.

Observing Auroræ (see also p. 38).—Those in favourable latitudes should watch during the more active portion of the sunspot period, or when there is considerable solar activity, especially near the equinoxes.

Arcs and *Bands* stretch across the sky, and may have considerable persistence; the latter appear like portions of arcs. *Rays* or streamers seem to flicker, and are more or less radial to the band or arc; *Beams* are long bright rays, of exquisite green or red, like search-lights. *Curtains* have curious convolutions, and are more or less parallel to the horizon, the lower edge being most continuous. *Patches* are isolated oval or globular areas resembling faint but quite transparent clouds; *Diffuse Auroræ* are large areas, often coloured, with no definite outline. *Coronæ*, rare, but exceedingly fine, are large starfish-shaped ovals, with dark centre, from which bright narrow flickering bands may extend to the horizon. The *Dark Segment* is the gloomy portion of the sky beneath the arch or streamers, in which the stars may be hardly or not at all visible. Various types may be seen during a display.

In N. temperate latitudes, the centre of disturbance is in a northerly direction—not necessarily in the direction of the magnetic pole, as is often supposed; a patch, arc, or corona may be overhead, or even south of it. Rays often appear to flash or flicker, and in arcs and bands a flickering from side to side is sometimes seen—not always in the same direction—and portions may suddenly brighten up and become centres from which the disturbances appear to travel.

The chief points to notice are the type, colour, brightness as compared with the Milky Way, height of lower edge above the horizon, and width; direction of the centre of the disturbance (allow for 'magnetic variation' of the compass), and times of the various phases. Also note the barometer and thermometer readings, and direction and force of the wind.

The angular breadth and length of persistent arcs, bands, and patches, should be carefully gauged by reference to the distance between neighbouring stars; also the angular distance, from well-known stars, of the upper and lower edges. The notes should be repeated at intervals, the times being carefully noted, as the height and distance of the aurora might be calculated from simultaneous observations (send notes to the B.A.A., Auroræ Section, London).

VII. THE CARE AND USE OF THE TELESCOPE.

Astronomical Telescopes are of two kinds—refracting and reflecting. Both varieties are rated according to their 'aperture,' as the *clear* diameter of the large lens in refracting telescopes, or of the mirror in reflecting telescopes, is called.

The larger the aperture, the more powerful the telescope in 'light-gathering' power, *i.e.*, in rendering visible faint objects; and, as this power (theoretically) increases in proportion to the *square* of the diameter, a telescope of 3 inches aperture is twice as powerful as one of 2 inches, while a 4-inch has nearly twice the power of a 3-inch, or four times that of a 2-inch (actual ratios, 4, 9, 16). In refractors, however, the theoretical power falls off rapidly with increasing diameter, the ever-thickening object-glass absorbing more and more light, though reflectors under 10 ins. are not quite so powerful as refractors of equal size. For astronomical purposes, a 3-inch telescope is about the smallest that can be used with satisfaction, though pleasing views of many objects may be obtained with smaller telescopes of good quality.

Diam. Object Glass (clear aperture)	1 in.	1½ in.	2 in.	2½ in.	3 in.	3½ in.	4 in.	4½ in.	5 in.	6 in.	8 in.	10 in.	12 in.
Closest star divided (approx.)	4·56″	3·04″	2·28″	1·82″	1·52″	1·30″	1·14″	1·01″	0·91″	0·76″	0·57″	0·46″	0·38″
Faintest star shown („) mag.	9·0	9·9	10·5	11·0	11·4	11·7	12·0	12·3	12·5	12·9	13·5	14·0	14·4

THE REFRACTOR essentially consists of two convex lenses—(i) a large one of considerable focal length, known as the *object glass*, which forms at its focus an image of the distant star or other object, and (ii) a small lens of much shorter focal length: this is called the *eye-piece*, and is used to magnify the image formed by the object glass.

The Object Glass is the most important part of the refractor, as its excellence depends on the accuracy of the curves of the lenses, the highness of their polish, and their transparency. In all astronomical telescopes worthy of the name, the object glass is 'achromatic'; that is to say, it is composed of two (sometimes three) lenses of equal size, but made of glasses of different density. These are so proportioned as to form an image almost free from the false colours which are inevitably present when a bright object is viewed through an object glass consisting of a single lens. A good object glass requires to be treated with the most scrupulous care. Follow carefully the notes on p. 49.

THE REFLECTOR.—In this form of telescope a large, concave, parabolic-curved mirror takes the place of the object glass of the refractor. The large mirror is held in a cell at the lower end of the large tube. The rays of light from the object pass down the tube and are reflected back. The reflected, convergent rays are intercepted—

(1) In the 'Newtonian' form of telescope, either by a small, elliptical, plane mirror ('flat'), or by a right-angled totally-reflecting prism, which reflects them at right angles through the side of the telescope to the eye-piece.

(2) In the 'Cassegrainian' form, by a small convex mirror, which reflects them back again, through a hole in the centre of the large mirror to the eyepiece; or (3) in the 'Gregorian' form, by a small concave mirror.

The Newtonian and Cassegrainian forms, like refractors, give an inverted image; the Gregorian, an *erect* image. The Cassegrainian form gives a greater focal length and larger image than Newtonians of the same aperture and length, but its field of view is smaller and the image fainter. Great telescopes are sometimes designed to use both forms.

Mirrors are usually made of glass, on which a film of silver is deposited chemically; this is very easily tarnished (p. 49), and vaporised aluminium is now often used, which is about as efficient as fresh silver, lasts years with little deterioration, and reflects the ultra-violet rays and blue end of the spectrum better—of great advantage photographically—but the red and infra-red rays less efficiently. Stainless steel mirrors last well, but only give 65% efficiency, compared with the 90% average of fresh silver.

An unsilvered glass mirror and 'flat'—which reduce the sunlight and heat reflected by some 90%—enable solar observations to be made with fairly large apertures, giving improved definition; a dark glass or solar eyepiece, however, is still necessary.

Eye-pieces.—These are used to magnify the image formed by the object-glass or the large mirror. For very high powers, and in special cases, a single lens is sometimes used to minimise loss of light, but generally an eye-piece consists of two lenses—a *Field lens*, furthest from the eye; and an *Eye lens*, nearest the eye. These are mounted in a short tube which screws or, preferably, slips into the focussing-tube of the telescope.

Positive and Negative Eye-pieces.—Eye-pieces are of two types:—*(a) Positive*, in which the image-plane is outside the eye-piece—between it and the object-glass or mirror—so that it can be used with a micrometer. *(b) Negative*, which cannot be employed with a micrometer, as the image-plane lies inside the eye-piece.

Inverted Image.—All astronomical eye-pieces show the object inverted (unless used with Gregorians), but this is of no disadvantage in practice. To make the object appear right way up requires additional lenses, or prisms, which absorb light, making the image fainter with no compensating gain. Among many varieties of eye-pieces are the:—

Huygenian eye-piece (negative).—The most common form, two plano-convex lenses having their flat surfaces towards the eye. Note that, though negative, fine cross-wires can be inserted on its diaphragm, at the focus of the eye lens, for use in a "finder" (p. 46), or for "guiding" in celestial photography—using cement, or threading through small holes.

Ramsden eye-piece (positive).—Two plano-convex lenses with their plane faces outward. Field of view "flatter" than that of the Huygenian, *i.e.*, not so blurred round the edges when the centre is sharply focussed. Performs well on planets.

Tolles Solid Ocular (negative) is practically a Huygenian eye-piece made out of a single glass cylinder, the foci of its curved ends falling inside it. Transmits more light than the Huygenian, and gives very good definition when well made.

Orthoscopic eye-piece (positive) contains a triple field lens and a simple eye lens. It yields a flat field free from distortion, and is specially recommended for medium and high powers. ('Orthoscopic' means giving a correct image.)

Kellner eye-piece (positive). A convex or plano-convex field lens with a much smaller over-corrected plano-convex achromatic eye lens. Field very large, colourless, and 'orthoscopic'; low powers are suitable for comets and scattered objects.

Monocentric eye-piece (positive).—A triple cemented lens, particularly recommended for the critical study of lunar and planetary detail, as it gives exquisite definition, and freedom from 'ghosts': its small field is its weak point.

Barlow Lens.—A concave or concave-meniscus lens of about 3 inches negative focal length, mounted in a short tube—made a sliding fit—inside the eye-piece draw-tube, and placed behind the object-glass or mirror, 4 or 5 ins. from the eye-piece. It increases considerably the focal length of the object-glass or mirror, giving an image of double the size, more or less, according to its distance from the eye-piece. This valuable device, at the cost of a slight loss of light, and a tendency to form 'ghosts,' gives a flatter field and an increase of the powers of all eye-pieces used, thus doubling the set at small expense.

The magnifying power of a telescope depends entirely upon the ratio of the focal length (f_1) of the object-glass to that of the eye-piece (f_2), the formula being $f_1 \div f_2$; thus, with an object-glass of 36 inches focal length, and an eye-piece having a focal length of $\frac{1}{2}$ inch, the magnifying power will be 72 diameters, or "power 72" as it is termed. Note that, as the power is increased: (*a*) the image gets fainter, and the area included less; (*b*) stars pass more quickly across the field; and (*c*) the atmospheric disturbances are also magnified, as well as any vibrations of the stand or ground.

It is advisable to have at least three eye-pieces of different power:—

(1). One of low power with a large "field," (that is, showing a considerable area of the sky), for viewing comets, large and scattered clusters, and extended nebulæ, magnifying 8 or 10 times per inch of aperture. Thus, on a 3 in. telescope the power may be from 25 to 30, or for a 4-inch, 32 to 40. For average eyes, aperture × 4 gives *lowest* useful power.

(2). One of moderate power, magnifying 25 or 30 times to each inch of aperture = 75-100 for a 3-inch, 100-120 for a 4-inch.

(3). One of high power, magnifying 50 or 60 times to each inch of aperture =150-180 „ „ 200-240 „ „

When experience has been gained, the observer may sometimes use eye-pieces of still higher powers—the extreme limit of useful power being about 100 diameters per inch of aperture—but, as a rule, to advantage only on close double stars, when the telescope is of fine quality, and atmospheric conditions most favourable. Such nights are very rare.

To find Focal Lengths.—(*a*) *Object-glass or Mirror.* Remove the eye-piece and stretch a piece of semi-transparent paper over the end of the draw-tube. Point the telescope at the Moon, and focus her image on the paper screen; the measured distance between the back of the object-glass and the screen—in Newtonians, between the centres of the surfaces of the large mirror and flat, and thence to the screen—is, for practical purposes, the focal length required.

(*b*) *Huygenian Eye-piece.*—Divide twice the product of the focal lengths of the two lenses by the sum of their focal lengths; the quotient is the focal length of an equivalent single lens.*

To find the Power of an Eye-piece.—Make a scale with plainly-marked equal divisions. Set this up at a considerable distance away, and, holding both eyes open, view the scale through the telescope with one eye and directly with the other. The number of divisions on the scale, covered by the magnified image of one of them, is equal to the magnifying power of the eye-piece used. For low powers, a distant brick wall will serve as a scale.

Another method.—Focus the telescope on a star. Next morning, without altering the focus, point the telescope to the bright sky. When the eye is placed about 10 inches behind the eye-piece, there will be seen a small, clearly-defined disc of light. Measure the diameter of this disc by means of a Berthon Dynamometer (see p. 47) placed against the eye-piece—a pocket lens, of low power, should be used as an aid in doing this. The magnifying power of the eye-piece is found by dividing the clear diameter of the object glass by the measured diameter of the bright image.

To find the Diameter of the Field of an eye-piece, observe how long a star situated near the equator (for instance, δ Orionis, or γ Virginis) takes to pass centrally across the field from one side to the other. This time, expressed in minutes and seconds, when multiplied by 15, will give the diameter of the field in minutes and seconds of arc.

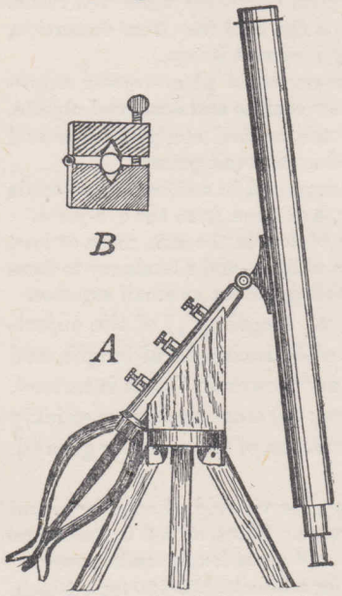
* When the distance apart of the lenses d is equal to half the sum of their focal lengths, $(f_1+f_2)\div 2$; the Rev. W. F. A. Ellison points out that as this distance is not always kept to, the correct formula for all combinations is:— $\Big\}$ Focal length $= \frac{f_1 \times f_2}{f_1+f_2-d}$.

TESTS.

The actual performance of a telescope on a celestial object is the only really satisfactory test. Seen through a telescope bearing its highest power, a fixed star of the second magnitude should appear as a minute, well-defined, circular disc of light, almost a point, and surrounded by one or two thin, concentric, bright rings. There should be no false rays of light, and the rest of the field should be uniformly dark. The telescope should not, however, be condemned too hastily, as an inferior eye-piece, or the state of the air (see p. 39), may be responsible for apparent defects in the object glass. A close double star with very unequal components forms a most severe test. A telescope of the finest quality should separate a double, consisting of two 6th magnitude stars, whose distance from centre to centre in seconds of arc is equal to 4·56 divided by the aperture expressed in inches. (see Table p. 44).

ACCESSORIES.

Stands.—Much depends upon the rigidity of the telescope stand, and good observations must not be expected from the open window of an ordinary room, as the vibration of the floor, and the mixed currents of air, set the object being viewed dancing. For small telescopes, the ordinary, alt-azimuth, tripod garden stand is most convenient. An iron pipe of about 4 inches diameter, partly sunk in the ground, and rammed full of clay to deaden vibration, forms a good support for a telescope of moderate size.



The Equatorial Stand is of enormous advantage, but is rather expensive. It has one of the pivots, or axes, which carries the telescope, directed towards the celestial pole, (being adjustable for latitude). The result is that a star may be followed by a single circular movement of the telescope, instead of the instrument having to be moved both in altitude and azimuth. A make-shift is to screw to the stand top a wooden block cut off at an angle, as shown in the illustration (A), and which has a V-groove, with sides at an angle of 60°, cut along the inclined face, for receiving the pillar. The claw legs of the stand, folded up, will act as a counterpoise, and two or three screw clamps will keep the pillar firm. A piece of hard wood (not shown in the illustration), also V-grooved, should be interposed between the point of the screws and the pillar, to prevent damage when tightening up the screws. A somewhat simpler construction is to hinge this upper block at one side to the lower block, and pass the screws through both blocks at the other side, as shown in the illustration at (B).

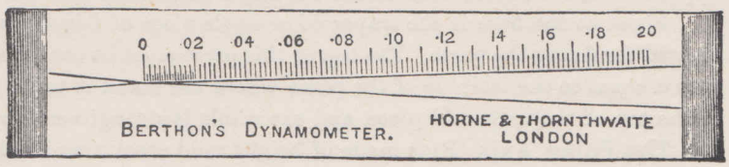
The angle of the sloping top, from the vertical, must be the latitude of the observer subtracted from 90°. Thus, for latitude 52° it will be $90° - 52° = 38°$.

Finder.—A finder is a small telescope fixed by supports to the body of the larger instrument. When high powers are used, this adjunct is a necessity, and in all cases it adds much to the comfort of observing. The finder may be roughly adjusted by day on a distant weather-cock or some other definite object. To improve the adjustment, bring the polar star into the centre of the field of a low power eye-piece on the large telescope; then alter the direction of the finder, by means of the adjusting screws, until the star image is in the centre of the field of the telescope, and also bisected by the cross wires of the finder at the same moment. Now replace the low-power eye-piece by one of high power, and perfect the adjustments in the same way. For small telescopes up to 3-inch, 'sights' similar to those on rifles can be arranged (painted white), which will be found of some service.

Dew-cap.—To guard against the deposition of dew on the object glass, make a tube of tin, cardboard, or some such material, about 9 inches or 1 foot long, and of such a diameter as to fit closely, but not too tightly, on to the object glass end of the tube. The inside of the dew-cap should be covered with black velvet, or painted with a mixture of lamp-black and size. Black blotting paper is also suitable.

Star Diagonal.—An L-shaped tube containing a right-angled totally-reflecting prism. One end of the fitting screws into the focussing-tube of the refractor, while the other end is screwed to receive an ordinary eyepiece. Its use prevents awkward positions of the body when viewing objects at high altitudes, but results in some loss of light and definition. A special diagonal is made for the Sun, which only requires a light shade glass (see note on p. 49).

Berthon's Dynamometer (or measuring gauge) is a little instrument used for measuring the diameters of small objects. It has two flat metal sides, the internal straight edges of which meet towards the end, and are inclined to each other at a small angle. One of the edges is graduated from 0 to $\frac{2}{10}$ of an inch. The figures on the scale denote the width of the gap between the two straight edges. To measure the diameter of any small object by means of this little appliance, it is only necessary to see at what part of the scale the object *just* fills the space between the internal edges of the gauge, and then take the reading from the scale. The scale is divided into 20 long divisions of ·01 or 1/100ths of an inch. These are subdivided into five parts, each equal to ·002 or 1/500ths of an inch. The first two long divisions are again divided into parts equal to ·001 or 1/1000ths of an inch.



Telescope House.—A tall folding clothes-horse, with a sheet fixed to it, and stayed by tent-ropes, forms a fair substitute, which will, to some extent, shield the telescope from vibration by the wind, and add to the observer's comfort.

TO CONSTRUCT A SIMPLE EQUATORIAL OR ALT-AZIMUTH STAND.

By following the directions and studying the diagrams given, any handy amateur, with the aid of a few simple tools, will be able at a very low cost to construct an efficient equatorial or alt-azimuth stand for a 3-inch or smaller refracting telescope. If made on a larger scale and of considerably thicker materials, the equatorial head here described, mounted on short, strong, fixed legs, would do equally well for a reflecting telescope of moderate size.

The Legs.—Take 3 deal boards about 6 to 6½ feet long, 5 inches wide, and 1 inch thick. Mark a point 2 inches from an edge at one end of the board and another point 3 inches from the same edge at the other end. Join the points found with a straight line and saw along it. This will divide the board into two equal flat pieces, each 1 inch thick, and tapering from 3 to 2 inches in width. These two pieces are joined together at distances of 1 inch and 9 inches from the narrow bottom end by 1¾-inch screws (No. 9 or No. 10, about $\frac{3}{16}$ inch diameter). The two laths are kept apart by blocks of hardwood cut from a piece having a 2 inch square section, and held in place by screws. Thus the leg is formed as shown in Fig. 1, which is on a scale three times less than that of Figs. 2, 3 and 4. The laths should not be screwed together until the brass plates mentioned later on have been fitted. A metal plate (*p*) sawn or filed to a blunt point, may be screwed to the *inner* side of the foot, with the point projecting.

The Top of the Stand.—This is best made from an iron casting, for which a wooden pattern will be required. The pattern is made of ¼-inch mahogany fretwood, cut to the shape shewn in Fig. 2, and strengthened by having a 4-inch bevelled disc of the same material glued and screwed on to it, so that the central part is ½ inch thick. Each of the three projecting parts of the casting is either drilled with two ¼-inch holes, each ¼-inch distant from the 3-inch edge, to receive ¼-inch bolts, or, as an alternative, $\frac{3}{16}$-inch holes may be drilled, and tapped ¼-inch Whitworth to receive metal screws. A ⅜-inch hole is drilled through the exact centre of the disc. Instead of the casting, a piece of tough, hardwood, such as beech, cut to the same shape, but at least 1¼-inches thick, may be used.

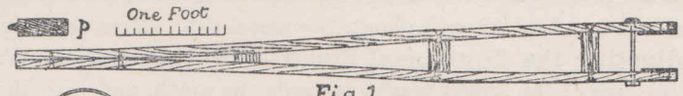


Fig 1.

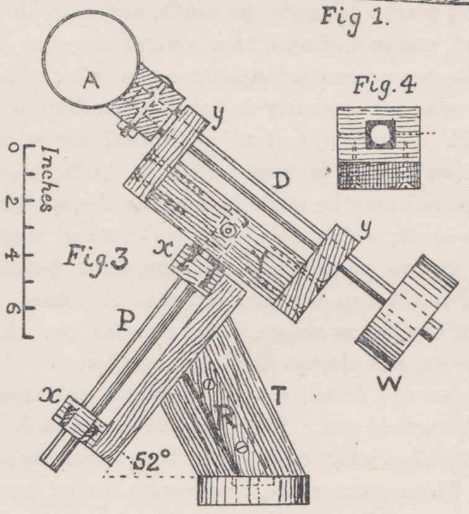


Fig. 3

Fig. 4

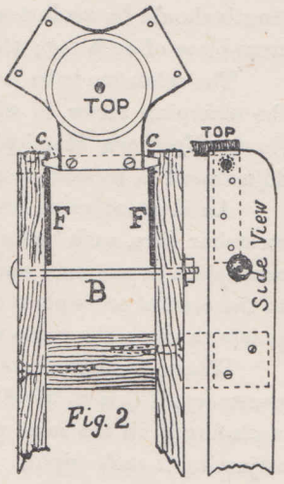


Fig. 2

The Leg Pivots.—Cut a 12-inch length of ½-inch *square* brass bar into three equal pieces. In a lathe, turn half-an-inch at each end into a blunted cone (C, Fig. 2), the small outer end being ⅜-inch in diameter. If no lathe, file the ends to the same shape as carefully as possible. These bars are now drilled with ¼-inch holes to correspond to the holes in the top, and are then screwed or bolted to the underside of the iron top.

The Hinge Plates.—To the top inner side, and towards the back of each of the laths forming the legs, is firmly screwed a flat, brass plate, 4 inches long, 1 inch wide and $\frac{3}{16}$-inch thick (Fig. 2, F, and side view). The plate is flush with the top of the leg, which is rounded off at the outer top corner, and has in it near the top a ⅜-inch hole slightly enlarged, and coned to fit over the conical pins at C. B is a ¼-inch bolt 6½ inches long, having a nut, bearing on a washer, which nut on being screwed up makes the hinge firm, and adjustable for wear.

The Equatorial Head (Fig. 3).—For this some pieces of oak or strong hardwood a full inch thick are required. The base is circular, and has, centrally fixed by screws in a recess in the bottom, a plate with a $\frac{3}{8}$-inch Whitworth tapped hole, to receive a screw which clamps the head to the stand. This plate might be fixed in a recess on the upper side of the round base before the angle piece next referred to is fixed in position.

Fixed to the base is the trapezoid or angle piece of 1-inch wood (T). Strong glue and $2\frac{1}{2}$-inch No. 12 screws should be used for fixing the parts. The top of this piece must be cut off at such a slope that the angle which it makes with the base is equal to the latitude of the place where the stand is to be used. A piece of wood 8 in. × 3 in. × 1 in. is screwed to the top of the trapezoid piece, and the whole is strengthened by adding the side pieces (R) which are 1 inch square.

The Polar Axis (P) is made of bright mild steel round rod, $\frac{3}{4}$-inch in diameter and $11\frac{1}{2}$ inches long. This steel is easily obtainable at large tool and material stores. The upper end of the polar axis (P) is driven into a rather smaller hole in the block (Y) which is of hardwood 6 inches long by 2 inches square. Care must be taken to make this hole at right angles to the block. A $\frac{1}{4}$-inch hole is drilled through block and axis, and a bolt inserted.

The Bearings (x, x) may be simply holes ($\frac{3}{4}$-inch) in the hardwood blocks, with a simple split arrangement for taking up wear; but it is more satisfactory to enlarge and square (slightly undercutting) the greater part of each hole, and, with the axis in place, to pour in melted tin or pipe composition (lead and tin) to form more durable bearings. Before pouring the lead, coat the axis with a mixture of black lead and water and allow it to dry. If, when all is cold, the axis cannot be twisted round, when oiled, it should be *gently* hammered endways with a mallet. If there is still trouble, cut with an old saw along the dotted line (Fig. 4), through wood and bearing-metal down to the axis. The upper halves of the split bearings can then be held in place by screws. Similarly for the bearings (y, y).

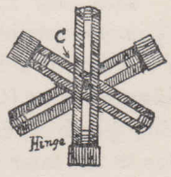
The Declination Axis (D), another $\frac{3}{4}$ inch steel rod, about 14 inches long, is fixed, like the polar axis, at right angles in an 8 inches long, 2 inches square block, grooved for its whole length on one side to receive the telescope main tube (A). The telescope is fixed to the block by means of leather straps or thin metal bands. Thin $\frac{3}{4}$-inch metal washers are placed between the blocks and the upper bearings of both axes. The balance-weight or counterpoise (w) is formed of a small round tin filled with lead, in which a piece of tube that just slides over the axis has been centrally fixed before the molten lead is poured in. The weight is so adjusted that it will counteract any tendency of the telescope to swing round by its own weight on the polar axis. It would be quite possible to fit graduated circles to this simple head. Celluloid circles can be obtained cheaply, and could be mounted on wooden discs of the same size —an addition which, with a carefully adjusted stand, will make possible the finding of Mercury and Venus in bright daylight and of stars by night from the places given in catalogues. But, even without circles, the advantage of being able to watch a star by only one movement will be found to be a great one.

Alt-azimuth Head.—For this only the parts A, D, Y, W (Fig. 3) are required. The polar axis P is replaced by a $\frac{3}{8}$-inch bolt which passes vertically and without shake through the central hole in the metal top of the tripod. A flat brass plate is screwed to, and protects from wear, the lower side of the block Y, which rests horizontally upon, and can be turned in azimuth about, the metal top. Turn or scrape the top flat, and grease with vaseline.

Adjusting the Equatorial Stand.—The completed stand is set up so that the top of the stand is level, with one of the legs of the tripod placed towards the south, and with the legs set well apart. Three strong cords of equal length should be made taut, one end of each to a central ring and the other end to a screw ring, fixed in the central cross-piece of each leg; this is a precaution against a possible accident.

The telescope tube is next set as nearly as possible parallel to the polar axis, and then, having slightly loosened the clamping screw, it will be sufficient, if no graduated circles are used, to gradually turn the equatorial head till (in the Northern Hemisphere) the Pole Star is seen in the field of view. The head is then clamped. Any slight adjustment in latitude required may be made by moving the southern leg of the tripod either inwards or outwards.

An alternative to the cords, which also renders the stand more rigid, is the addition of three stretcher bars, each made of two parallel metal strips, fixed $\frac{3}{8}$-inch apart, and riveted to a short cross-piece at one end, and to the flap of a firm hinge at the other. The other hinge-flap is screwed to the central cross-piece of the leg, as shown in the illustration. A $\frac{3}{8}$-inch bolt with a wing nut (*c*) passes through the three slots, and clamps the bars together.



When graduated circles are fitted, a more accurate adjustment of the equatorial head is necessary, if it is to be of practical use. With a movable stand it is well to have some means of replacing it in the same position when once it has been carefully adjusted, or much valuable time may be lost in re-adjusting it each night. Three stone slabs, or concrete blocks, having central gun-metal or brass plugs inserted, are set in the ground at the corners of an equilateral triangle equal in size to the most convenient leg base. Each metal plug has a hole or recess in the top, in which rests the previously-mentioned metal spike attached to the lower end of the leg. The adjustment of the head proper may be effected by means of thin wedges under the head, or, better, by three screws passing through the metal top of the tripod and bearing on the under side of the base of the head, which should be protected by a circular metal plate that rests on the points of the adjusting screws.

The true N. pole, towards which the polar axis should be directed as nearly as possible, lies about 1° (two Moon breadths) distant from Polaris, and very nearly on the straight line joining Polaris and η Ursæ Majoris—the last star in the tail of the Great Bear. If the time is chosen when the Pole star transits above or below the pole (see *N.A.*), and the telescope (set as before, parallel to the polar axis) is directed towards the Pole star, so that it appears in the centre of the field of view, then a lowering or a raising of the axis through 1°, by means of the southern adjusting screw, will make the adjustment sufficiently accurate for finding an object when using an eye-piece of low power.

HINTS ON CLEANING.

Refracting Telescope.—A good object glass is so delicately figured that it should be cleaned as rarely and carefully as possible, for fear of affecting the accuracy of its form. (*See below*, "*Cleaning.*")

The lenses should never be taken out of their cell by an inexperienced person.

The object glass should be held in its cell with just sufficient "play" for a slight rattle to be heard when it is gently shaken. If screwed up tightly, it causes strains in the glass which mar the perfect definition.

Reflecting Telescope.—The silvered mirror requires to be kept with very special care, as the silver is exceedingly liable to tarnish, especially in or near large towns, from the sulphurous fumes in the air. The owner of a reflecting telescope should, therefore, procure and study the "Hints on Reflectors," which have been published by several of the leading makers of these instruments.

A slight stain causes merely an inconsiderable loss of light, but, if badly tarnished, the mirror must be re-silvered. This process may be successfully accomplished by the amateur, with little difficulty, and at no great expense, if he carefully follows the directions given in the books just referred to, and uses pure chemicals.

Care of the Telescope.—Before removing the telescope after the night's work, cover the object glass or mirror with the metal cap provided for that purpose.

Never take the instrument from the cold outer air into a warm room, or the object glass will become dewed. If this should happen, the object glass must not be left in that state; but it should be placed in a warm room, at a safe distance from a fire, until the moisture has vanished. Any stains left on the glass must be removed by gentle polishing. Never wipe an object glass when it is damp.

Cleaning the Lenses.—When it becomes necessary to clean these, any dust should first be removed by means of a *camel's-hair brush.* Then the lens should be wiped very gently with a piece of very fine and clean wash-leather or silk.

When not in use, all brushes and materials employed for this purpose should be carefully protected from dust by keeping them in clean stoppered bottles or air-tight cases.

Solar Eye-pieces.—The use of a silvered or deeply-coloured Barlow lens with an ordinary eye-piece is a simple and effective way of reducing the Sun's light and heat. The chief objection to the silvered lens is that the film is so easily scratched. A special solar diagonal (Sir J. Herschel's), in which only about $\frac{1}{20}$th of the Sun's light is reflected from the first surface of a narrow prism, is procurable. With this, the addition of a light shade-glass is necessary. See illustration in Proctor's *Half-Hours with the Telescope*, new edn.

Helioscopes, or Helioscope eye-pieces, depending upon polarization, reduce the Sun's light sufficiently to enable a dark-glass to be dispensed with, but they are somewhat complicated and expensive appliances.

Spectroscopes.—Small instruments for viewing stellar spectra can be had at a comparatively low price; these screw on to or fit in the eye-piece tube. Those for viewing prominences, however, are much more expensive, as the dispersion required is considerable, and prices are of the order of £7 ($35) upwards. It would be a great boon to amateur astronomers if some enterprising optician could bring out a satisfactory instrument for half that sum, or less.

Astronomical Photography.—Anyone possessing an equatorial telescope with a slow worm-wheel motion on the polar axis, can take good stellar (or cometary) negatives in a box camera attached to the tube of the telescope, using ordinary photographic lenses of *f*/6 or greater aperture, which should be carefully focussed by trial exposures; a driving clock is not essential, though advantageous. The telescope serves as a 'guider,' a star being kept steadily on cross-wires in the eyepiece; these wires can easily be added to a positive eyepiece by anyone accustomed to use tools. Exposures are rather lengthy, from some twenty minutes upwards—to hours for faint stars—and require patience.

Most refractors are not very suitable for taking photographs of the Sun and Moon in the telescope itself, without an eyepiece, as they do not bring the actinic and visual rays to the same focus, and the sharpest position has to be found by trial and error. Reflectors are free from this disadvantage, also 'photo-visual' refractors; but the latter are expensive. The Moon can be taken by a fixed telescope, of ordinary focal length, in about $\frac{1}{4}$-second, but the image is small—in a 3-inch, only $\frac{1}{8}$-inch diameter.

Those desirous of taking up this pursuit should procure 'Astronomical Photography,' by Mr H. H. Waters, F.R.A.S.—a little book which gives all needed information on the subject of apparatus, adjustment, exposure, &c.

A Celestial Globe, adjustable for latitude, is useful for finding the direction and altitude of Mercury, or a comet, in twilight, also the path of the Zodiacal Light. The stars are reversed as regards left and right on the globe, because we view the star sphere from the inside, and the globe is viewed from the outside.

ADJUSTMENTS OF A NEWTONIAN REFLECTOR.

The elliptical flat mirror, mounted in a short metal tube cut off at an angle of 45° with its axis, is sometimes supported in the centre of the main tube and towards the upper end of it, by a single radial arm fixed to the inside of the tube. More usually the support consists of three, sometimes four, steel strips of spring temper fitted with screwed ends that pass through holes in the main tube, outside which they are held firmly by means of nuts. With the aid of compasses or a scaled ruler set the centre of the flat mounting exactly in the centre of the tube, if it is not already so placed.

When the flat has been centred, its inclination must be adjusted so as to reflect a ray of light passing along the axis of the main tube along the axis of the eyepiece focussing tube. This must be done by means of the adjusting screws fitted to the flat mount. Sometimes these are three in number, but a better arrangement is a hinged flat mount with a single angle-adjusting screw with a knurled head, and an axial screwed pin enabling the flat to be partly rotated and clamped in position by means of a heavy knurled nut.

A brass disc-fitting, with a central hole about $\frac{1}{20}$in. in diameter, is screwed or slid into the eyepiece draw-tube in place of the eyepiece. A special fitting, though convenient, is not indispensable, since the front part of the mount of an eyepiece of high power, with the lenses removed, will do well as a substitute. On looking through this hole, there will be seen the circular end of the eyepiece tube and within it the flat with an apparently circular outline. If the flat is approximately adjusted there will appear, within the circle of the flat, the circular outline of the mirror and its cell. As a help to the eye, the large mirror may be covered with a white circular card of the same size as the mirror. Then, by means of the flat adjusting screws, gradually tilt the flat until the outline of the mirror (or cardboard disc) is concentric with the eyepiece-tube circle. It may be necessary to move the base of the focussing-tube mount slightly up or down the main tube to perfect this adjustment. Remove the card and there will be seen a circular dark spot, the image of the flat. If this is not exactly in the centre of the bright mirror image, it must be brought to that position by means of the three adjusting screws at the base of the large mirror cell. *The dark spot is always most distant from the adjusting screw that must be turned in.* Thus, in Fig. 1, the screw whose position is indicated by the head of the arrow must be turned in to bring the dark spot to the centre. The same result is achieved by turning the two other screws equally outwards. The circular outline of the flat itself should not be exactly concentric with the eyepiece tube and mirror circles, but *slightly* displaced towards the upper end of the tube, as shewn in Fig. 2 where all is in perfect adjustment. EE, the outermost circle represents the far end of the eyepiece tube; T part of the tube which holds the flat; FF the flat itself; MM the bright image of the large mirror; I the dark central image of the flat, and S the images of the four spring supports of the flat mount.

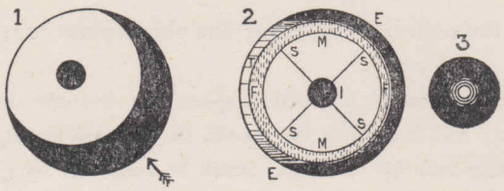


Fig. 3 shows the appearance of a moderately bright star in a good telescope, when the air is steady and the instrument correctly adjusted and carefully focussed—a bright round spot surrounded by two or three concentric rings of light. It is impossible to portray accurately the extreme delicacy of these diffraction rings as they appear on the best observing nights.

EQUATORIAL ADJUSTMENTS.

It is infeasible here to give full directions for the accurate adjustment of an equatorial. Such instructions are given in Horne and Thornthwaite's "Hints on Reflecting and Refracting Telescopes," and in Chambers' "Handbook of Descriptive and Practical Astronomy," Vol. II. (Clarendon Press, 1890). The chief adjustments are :—

1. *Adjust the vernier-index of the declination circle.* The equatorial being placed in nearly its correct position, read the declination of a star brought to the centre of the field when near its southing with the circle facing E. Repeat with the circle facing W. If the two readings agree, the vernier position is correct; if they are not the same, move the vernier half the difference between them. Other adjustments having been completed, the declination vernier will indicate 0° when the telescope points to the equator.

2 *Adjust the polar axis to the altitude of the Pole.* Read the declination of a star which is on, or nearly on the meridian, and also near the zenith. Compare the reading with the declination of the star as given in the Nautical or Whitaker's Almanac. If the amounts differ, set the circle to the correct reading, and bring the star to the centre of the field by means of the base adjusting screw (S^1 in the drawing on page 51).

3. *Place the polar axis in the meridian.* Point the telescope to a known star about 6 hours from the meridian, either E. or W. of it, but as distant as possible from both Pole and horizon. If the star is E. and its declination as shown on the declination circle exceeds that given in the catalogue, the lower end of the polar axis is W. of its right place and must be moved. A horizontal or azimuth movement given to the equatorial head to correct the declination corrects also the meridian position

Other adjustments necessary are :—

4. *Set the optical axis of the telescope at right angles to the declination axis.*
5. *The polar and declination axes must be set at right angles.*
6. *The index of the hour circle must point to* 0^h *when the telescope is in the meridian and the declination axis horizontal. With a movable hour circle (see opposite), the verniers* V^2 *and* V^3 *should show like readings when the telescope is thus set.*

EQUATORIAL HEAD.

THE section drawing represents an equatorial head designed and made by the author. It is suitable for a 4-inch or smaller refractor. It was built up of iron and gunmetal castings from simple wood patterns, and a few mild steel and brass rods. All the work required is within the capacity of a $3\frac{1}{2}$-in. centre foot lathe, with the addition of a single division plate and cutter for the teeth of the R.A. circle, and a circular protractor for the marking of the divisions on the circles.

A. Part of the driving-rod with universal joint U at the upper end, connecting with the worm screw, and a handle (not shewn) at the lower end.

B. Gunmetal coned bearings of the polar axis.

C. Declination circle.

D. Declination axis.

E. Arm screwed to the polar axis tube and adjustable for any latitude.

F. One of two side plates screwed to the base and between which E is held by a $\frac{1}{2}$-in. bolt and nut I.

H. Lever of cam. When pulled down it puts the worm into gear with the fixed toothed ring JJ.

K. Knurled head to turn a pinion engaging with a circle of teeth cut on the inner side of the R.A. ring R.

L. Bolt passing through a hole in the base, slotted to allow for a slight movement in azimuth.
Behind L is a central vertical pin ($\frac{3}{8}$-in. in diameter) about which the whole head can be turned.

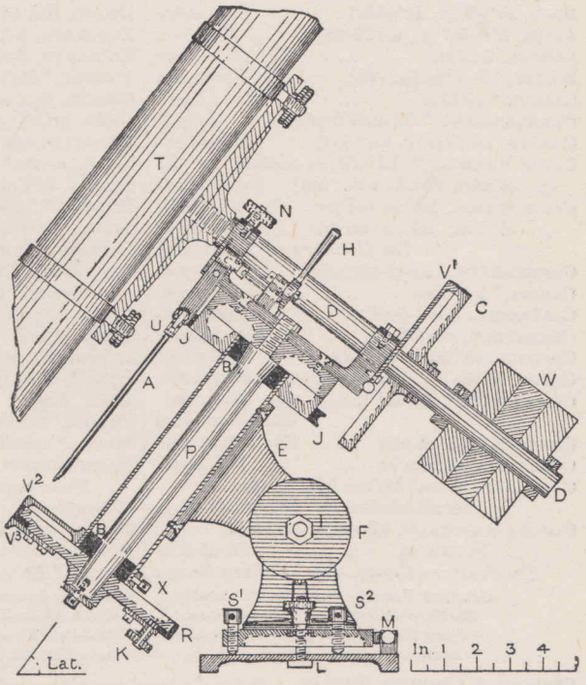
M. One of two push screws for exact meridian setting.

N. Knurled declination clamp nut.

P. Polar axis.

R. Right Ascension Ring, marked from 0h. to 24h., from west to east round by south.

S^1. Adjusting screw for the slow adjustment of the tilt of the polar axis.



S^2. One of the two other base screws.

T. Main tube of the telescope.

V^1. Declination Vernier on arm with adjusting push screws at the lower end.

V^2. R.A. Vernier, fixed, for time.

V^3 R.A. Vernier, moving, for R.A. of object.

W. Counterpoise weights with set collars.

No slow motion in Declination is shewn, but one is a great convenience and could easily be added to the head. For convenience of representation V^2 is shown at right angles to its correct position. It may be rotated about the turned end of the polar axis tube, and clamped in position by the screw X.

A large-faced watch or an ordinary spring clock, regulated to keep sidereal time, with an inner circle of figures, XIII to XXIV added to the face, is a most useful, indeed almost indispensable adjunct. This may be set correctly to sidereal time each day by means of the wireless time signal. The sidereal time for the previous midnight can be obtained from Whitaker's or the Nautical Almanac, and to this $12^h\ 1^m\ 58^s$ (say $12^h\ 2^m$) must be added to get the sidereal time at noon. *

The method of finding a celestial object with an equatorial of this type is simple. (1) Move the telescope so that the declination vernier (V^1) indicates the declination of the object as given in the catalogue. Clamp in declination. (2) By means of the knurled head (K) turn the R.A. ring till the R.A. of the object is shewn by the lower or moving vernier (V^3). (3) Turn the telescope till the sidereal time as read from the clock is shewn also by the upper fixed vernier (V^2).

If a low or medium power is used and the head is in correct adjustment, the object should be in the field of view. The lever (H) is then pulled down, and the object can be followed by slowly turning the driving rod (A).

If the object is not at first in the field of view, a slight movement of the telescope either forwards or backwards in R.A. will generally bring it into sight. If not, the circle readings should be checked and the adjustments of the head corrected if necessary.

The head should be fixed on a strong wooden braced tripod or iron pipe filled with concrete and protected from the weather by a galvanized iron hood, the telescope itself having been removed.

** For places E. of Greenwich a correction of 1m. of time must be added for each 15' of longitude; if W. subtracted.*

THE BRIGHTEST AND THE NEAREST STARS.

Name	1950 R.A.	1950 Dec.	Magnitude Apparent	Magnitude Absolute	Parallax	Distance L't. yrs.	Distance Parsecs	Annual P.M.	Luminosity (Sun=1)	Spectral Type
BRIGHTEST STARS.										
Sirius	$6^h\ 43{\cdot}0^m$	$-16°\ 38'$	−1·58	1·3	0″·371	9	2·7	1″·32	26	A0
Canopus	6 22·8	−52 40	−0·86	−7·4 ?	0″·005 ?	650 ?	200 ?	0″·02	80,000 ?	F0
α Centauri	14 36·5	−60 38	0·06	4·7, 6·1	0″·758	4	1·3	3″·68	1·1, 0·2	G0, K5
Vega	18 35·2	+38 44	0·14	0·6	0″·124	26	8·3	0″·35	50	A0
Capella	5 12·9	+45 58	0·21	−0·6	0″·069	47	14·5	0″·44	150	G0
Arcturus	14 13·4	+19 28	0·24	−0·2	0″·080	41	12·5	2″·29	100	K0
Rigel	5 12·1	− 8 15	0·34	−5·8 ?	0″·006 ?	540 ?	166 ?	0″·01	18,000 ?	B8
Procyon	7 36·8	+ 5 22	0·48	3·0	0″·312	10	3·2	1″·24	5	F5
Achernar	1 35·9	−57 30	0·60	−0·9	0″·049	66	20·4	0″·09	200	B5
β Centauri	14 0·3	−60 7	0·86	−3·9	0″·011	300	91	0″·04	3,000	B1
Altair	19 48·3	+ 8 43	0·89	2·4	0″·204	16	5·0	0″·66	9	A5
Betelgeuse	5 52·5	+ 7 24	0·92 v.	−2·9	0″·017	190	62	0″·03	1,200	M0
α Crucis	12 23·7	−62 50	1·05	−2·7, −2·2	0″·014	230	71	0″·05	1,000; 650	B1, B1
Aldebaran	4 33·0	+16 25	1·06	−0·1	0″·057	57	17·5	0″·21	90	K5
Pollux	7 42·3	+28 9	1·21	1·2	0″·101	32	10·0	0″·62	28	K0
Spica	13 22·5	−10 54	1·21	−3·1	0″·014	230	71	0″·05	1,500	B2
Antares	16 26·5	−26 20	1·22	−4·0	0″·009	360	111	0″·03	3,400	M0
Fomalhaut	22 54·8	−29 53	1·29	2·0	0″·137	24	7·2	0″·27	13	A3
Deneb	20 39·7	+45 6	1·33	−5·2 ?	0″·005 ?	650 ?	200 ?	0″·00	10,000 ?	A2
Regulus	10 5·7	+12 13	1·34	0·2	0″·058	56	17·2	0″·24	70	B8
β Crucis	12 44·8	−59 25	1·50	−2·5	0″·016	200	62·5	0″·05	850	B1
Castor	7 31·4	+32 0	1·58	1·4, 2·2	0″·076	43	13·2	0″·20	23; 11	A0, A0
NEAREST STARS.										
Proxima Centauri	$14^h\ 26{\cdot}5^m$	$-62°\ 29'$	10·5	15·5	0″·79	4·2	1·2	3″·85	0·0001	M ?
α Centauri	14 36·5	−60 38	0·06	4·7, 6·1	0″·76	4·3	1·3	3″·68	1·1, 0·2	G0, K5
Munich 15040	17 55·3	+ 4 29	9·7	13·4	0″·54	6·2	1·9	10″·29	0·0005	M
Lalande 21185	11 0·6	+36 20	7·6	10·7	0″·42	8·3	2·4	4″·78	0·005	M2
Wolf 359	10 53	+ 7 30	13·5	16·5	0″·40	8·1	2·5	4″·84	0·00002	M4
Sirius A	6 43	−16 38	−1·6	1·3	0″·37	8·7	2·7	1″·32	26·0	A0
Innes' Star	11 14·2	−57 18	11·7	14·4	0″·34	9·6	2·9	2″·69	0·0001	—
B.D. −12° 4523	16 25·4	−12 28	9·5	12·1	0″·33	9·9	3·1	...	0·0015	M5
Corboda Vh.243	5 9·5	−44 57	9·2	11·7	0″·32	10·2	3·2	8″·75	0·0022	M0
Ross 248	23 38	+43 50	13·8	16·3	0″·32	10·2	3·2	...	0·00003	M6
τ Ceti	1 41·8	−16 13	3·6	6·1	0″·32	10·2	3·2	1″·92	0·35	K0
Procyon	7 36·8	+ 5 22	0·5	3·0	0″·31	10·4	3·2	1″·24	5·5	F5
ε Eridani	3 30·6	− 9 38	3·8	6·3	0″·31	10·5	3·2	0″·97	0·31	K0
61 Cygni	21 4·5	+38 29	5·6	8·0	0″·30	10·7	3·3	5″·25	0·06	K5
Lacaille 9352	23 2·4	−36 9	7·4	9·7	0″·29	11·2	3·4	6″·90	0·013	M0
Σ 2398	18 42·3	+59 33	8·8	11·1	0″·29	11·3	3·5	2″·31	0·0036	M4
Groombridge 34	0 15·4	+43 44	8·1	10·4	0″·28	11·6	3·6	2″·89	0·0073	M2
ε Indi	21 59·3	−56 59	4·7	6·9	0″·28	11·6	3·6	4″·69	0·17	K5
Krüger 60	22 26·3	+57 27	9·3	11·4	0″·26	12·5	3·8	0″·87	0·003	K5
Van Maanen's	0 46·2	+ 5 10	12·3	14·3	0″·25	12·8	3·9	3″·01	0·0002	F0
Lalande 8760	4 37	−38 0	6·7	8·6	0″·25	12·9	4·0	3″·53	0·04	M0
O.A. (N) 17415	17 37	+68 23	9·3	11·2	0″·24	13·2	4·1	1″·33	0·003	K
B.D. 51° 658	2 52	+52 12	9·2	11·1	0″·24	13·6	4·2	...	0·004	...

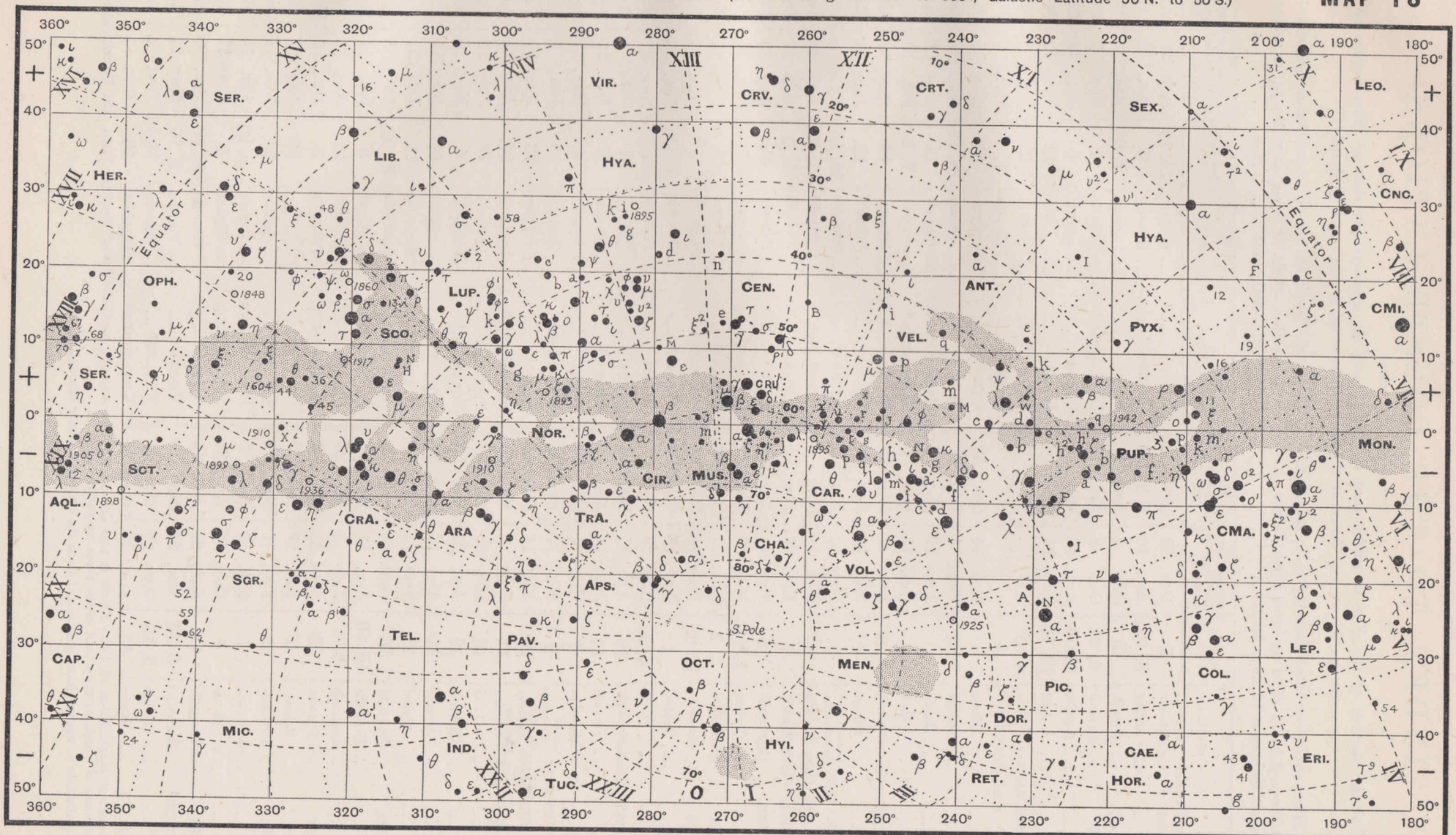
BAYER AND LACAILLE LETTERS AND FLAMSTEED NUMBERS.

ANDROMEDA.	A, 49	b, 60	c, 62							
AQUARIUS.	A^1,103	A^2,104	b^1, 98	b^2, 99	b^3,101	c^1, 86	c^2, 88	c^3, 89	d, 25	e, 38
	f, 53	g, 66	h, 83	i^1,106	i^2,107	i^3,108	k, 3			
AQUILA.	A, 28	b, 31	c, 35	d, 27	e, 36	f, 26	g, 14	h, 15	i, 12	l, 71
BOOTES.	b, 46	c, 45	d, 12	e, 6	f, 22	g, 24	h, 38	i, 44	k, 47	
CANCER.	A^1, 45	A^2, 50	b, 49	c, 36	d^1, 20	d^2, 25				
CAPRICORNUS.	A, 24	b, 36	c, 46							
CASSIOPEIA.	A, 48									
CENTAURUS.	g, 2	h, 4	i, 1	k, 3						
CYGNUS.	A, 68	b^1, 27	b^2, 28	b^3, 29	c, 16	d, 20	e, 26	f^1, 59	f^2, 63	g, 71
	P, 34									
DRACO.	A, 15	b, 39	c, 46	d, 45	e, 64	f, 27	g, 18	h, 19	i, 10	
ERIDANUS.	A, 39	b, 62	c, 51	d, 43	l, 53	v, 17	w, 32	S, 64		
GEMINI.	A, 57	b, 65	c, 76	d, 36	e, 38	f, 74	g, 81			
HERCULES.	A,104	b, 99	d, 59	e, 69	f, 90	g, 30	h, 29	i, 43	k, 47	l, 45
	m,36,37	n, 28	o, 21	r, 5	t, 107	u, 68	w, 72	x, 77	y, 82	z, 88
HYDRA.	A, 33	a, 6	k, 51	l, 52	m, 54	D, 12	E, 58	P, 27		
LEO.	A, 31	b, 60	c, 59	d, 58	e, 87	f, 15	g, 22	h, 6	k, 52	l, 53
	m, 51	n, 73	o, 95	p^2, 61	p^3, 62	p^4, 65	p^5, 69			
LUPUS.	f, 2	i, 1								
OPHIUCHUS.	A, 36	b, 44	c, 51	d, 45	f, 53					
ORION.	A, 32	b, 51	c, 42	d, 49	e, 29	f^1, 69	f^2, 72	g, 6	h, 16	i, 14
	k, 74	l, 75	m, 23	n^1, 33	n^2, 38	o, 22	p, 27			
PERSEUS.	A, 43	c, 48	d, 53	e, 58	f, 52	g, 4	i, 9	l, 32	m, 57	n, 42
	o, 40									
PISCES.	A, 5	b, 7	c, 32	d, 41	e, 80	f, 89	g, 82	h, 68	i, 65	k, 67
	l, 91									
SAGITTARIUS.	A, 60	b, 59	c, 62	d, 43	e^1, 54	e^2, 55	f, 56	g, 61	h^1, 51	h^2, 52
SCORPIUS.	A, 2	b, 1	c^1, 12	c^2, 13	i, 22	o, 19				
SERPENS.	A^1, 11	A^2, 25	b, 36	c, 60	d, 59					
TAURUS.	A^1, 37	A^2, 39	b, 79	c, 90	d, 88	e, 30	f, 5	h, 57	i, 97	k, 98
	l, 106	m,104	n, 109	o, 114	p, 44	q, 19	r, 66	s, 4	t, 6	u, 29
URSA MAJOR.	A, 2	b, 5	c, 16	d, 24	e, 18	f, 15	g, 80	h, 23		
VIRGO.	A^1, 4	A^2, 6	b, 7	c, 16	d^1, 31	d^2, 32	e, 59	f, 25	h, 76	i, 68
	k, 44	l, 74	m, 82	o, 78	p, 90	q, 21				

In this Atlas, Flamsteed numbers are used in preference to Roman letters, since the former generally follow in each constellation in order of Right Ascension, and thus the places of the numbered stars are the more easily found. But, as the letters are sometimes used (occasionally in the italic form), the above table has been prepared as an aid to the speedy identification of the star.

GALACTIC CHART (Galactic Longitude 180° to 360°; Galactic Latitude 50°N. to 50°S.)

MAP 18



o Principal Novae.

The stippled area represents the general position of the Milky Way.

Magnitudes. 0 1 1·5 2 2·5 3 3·5 4 4·5

INDEX TO THE CONSTELLATIONS.

With the number of the Map in which each is shown, and the approximate date of culmination of a point on its central hour of Right Ascension at 9 p.m. and Midnight.

For each Hour earlier or later than 9 p.m. or midnight—
Earlier—Add 15 days to dates given below.
Later—Subtract 15 days from „ „

For each Week earlier or later than dates below—
Earlier—Add 28 minutes to 9 p.m. or midnight
Later—Subtract „ from „ „

Name of Constellation	Genitive	See Map No.	Approx. Date Culmination 9 p.m.	Approx. Date Culmination Midnight
ANDROMEDA	Andromedæ	3	Nov. 23	Oct. 9
ANTLIA† ...	... Antliæ	8, 10	Apr. 10	Feb. 24
APUS† ...	... Apodis	16	July 5	May 21
AQUARIUS	... Aquarii	4, 14	Oct. 9	Aug. 25
AQUILA ...	... Aquilæ	13, 14	Aug. 30	July 16
ARA ...	... Aræ	12, 16	July 25	June 10
ARGO* (See CARINA, VELA, and PUPPIS)		8, 10, 16	...	...
ARIES ...	... Arietis	5	Dec. 14	Oct. 30
AURIGA ...	... Aurigæ	5, 7	Feb. 4	Dec. 21
BOÖTES ...	... Boötis	11	June 16	May 2
CAELUM† ...	... Cæli	6	Jan. 15	Dec. 1
CAMELOPARDUS†	Camelopardi	1, 2	Feb. 6	Dec 23
CANCER ...	... Cancri	7	Mar. 16	Jan. 30
CANES VENATICI†	Canum Venaticorum	9	May 22	Apr. 7
CANIS MAJOR	Canis Majoris	8	Feb. 16	Jan. 2
CANIS MINOR	Canis Minoris	7	Feb. 28	Jan. 14
CAPRICORNUS	Capricorni	14	Sept. 22	Aug. 8
CARINA† ...	... Carinæ	8, 16	Mar. 17	Jan. 31
CASSIOPEIA	Cassiopeiæ	2, 3	Nov. 23	Oct. 9
CENTAURUS	...Centauri	10, 16	May 14	Mar. 30
CEPHEUS ...	... Cephei	2	Nov. 13	Sept. 29
CETUS ...	... Ceti	4, 5	Nov. 29	Oct. 15
CHAMAELEON†	Chamæleontis	16	Apr. 15	Mar. 1
CIRCINUS†	... Circini	16	June 14	Apr. 30
COLUMBA†	Columbæ	6	Feb. 1	Dec. 18
COMA BERENICES†	Comæ Berenicis	9	May 17	Apr. 2
CORONA AUSTRALIS	Coronæ Australis	14	Aug. 14	June 30
CORONA BOREALIS	Coronæ Borealis	11	July 3	May 19
CORVUS ...	... Corvi	10	May 12	Mar. 28
CRATER ...	... Crateris	10	Apr. 26	Mar. 12
CRUX† ...	... Crucis	16	May 12	Mar. 28
CYGNUS ...	... Cygni	13	Sept. 13	July 30
DELPHINUS	...Delphini	13	Sept. 14	July 31
DORADO† ...	... Doradûs	15, 16	Jan. 31	Dec. 17
DRACO ...	...Draconis	1, 2	July 8	May 24
EQUULEUS	... Equulei	13	Sept. 22	Aug. 8
ERIDANUS...	... Eridani	6	Dec. 25	Nov. 10
FORNAX† ...	...Fornacis	6	Dec. 17	Nov. 2
GEMINI ...	Geminorum	7	Feb. 19	Jan. 5
GRUS† ...	... Gruis	4	Oct. 12	Aug. 28
HERCULES	...Herculis	11	July 28	June 13
HOROLOGIUM†	Horologii	6, 15	Dec. 25	Nov. 10
HYDRA ...	... Hydræ	8, 10	Apr. 29	Mar. 15
HYDRUS†...	... Hydri	15	Dec. 10	Oct. 26
INDUS† ...	... Indi	14, 15	Sept. 26	Aug. 12
LACERTA†	... Lacertæ	3	Oct. 12	Aug. 28
LEO ...	... Leonis	7, 9	Apr. 15	Mar. 1
LEO MINOR†	Leonis Minoris	9	Apr. 9	Feb. 23
LEPUS ...	... Leporis	6	Jan. 28	Dec. 14
LIBRA ...	... Libræ	12	June 23	May 9
LUPUS ...	... Lupi	12	June 23	May 9
LYNX† ...	... Lyncis	1, 7	Mar. 5	Jan. 19
LYRA ...	... Lyræ	13	Aug. 18	July 4
MENSA† ...	... Mensæ	15, 16	Jan. 28	Dec. 14
MICROSCOPIUM†	Microscopii	14	Sept. 18	Aug. 4
MONOCEROS†	Monocerotis	7, 8	Feb. 19	Jan. 5
MUSCA† ...	... Muscæ	16	May 14	Mar. 30
NORMA† ...	... Normæ	12	July 3	May 19
OCTANS† ...	...Octantis	15, 16	Circum polar	
OPHIUCHUS	Ophiuchi	11, 12	July 26	June 11
ORION ...	... Orionis	5, 6	Jan. 27	Dec. 13
PAVO† ...	... Pavonis	15	Aug. 29	July 15
PEGASUS ...	... Pegasi	3	Oct. 16	Sept. 1
PERSEUS ...	... Persei	5	Dec. 22	Nov. 7
PHOENIX†	Phœnicis	4	Nov. 18	Oct. 4
PICTOR† ...	... Pictoris	6, 16	Jan. 30	Dec. 16
PISCES ...	... Piscium	3	Nov. 11	Sept. 27
PISCIS AUSTRINUS	Piscis Austrini	4	Oct. 9	Aug. 25
PUPPIS† ...	... Puppis	8	Feb. 22	Jan. 8
PYXIS† ...	... Pyxidis	8	Mar. 21	Feb. 4
RETICULUM†	... Reticuli	15	Jan. 3	Nov. 19
SAGITTA ...	... Sagittæ	13	Aug. 30	July 16
SAGITTARIUS	Sagittarii	14	Aug. 21	July 7
SCORPIUS	... Scorpii	12	July 18	June 3
SCULPTOR†	Sculptoris	4	Nov. 10	Sept. 26
SCUTUM† ...	... Scuti	14	Aug. 15	July 1
SERPENS ...	Serpentis	11	July 21	June 6
SEXTANS†	Sextantis	9, 10	Apr. 8	Feb. 22
TAURUS ...	... Tauri	5	Jan. 14	Nov. 30
TELESCOPIUM†	Telescopii	14	Aug. 24	July 10
TRIANGULUM	Trianguli	3	Dec. 7	Oct. 23
TRIANGULUM AUSTRALE†	Trianguli Australis	16	July 7	May 23
TUCANA† ...	... Tucanæ	15	Nov. 1	Sept. 17
URSA MAJOR	Ursæ Majoris	1, 9	Apr. 25	Mar. 11
URSA MINOR	Ursæ Minoris	1	June 27	May 13
VELA† ...	Velorum	8, 10	Mar. 30	Feb. 13
VIRGO ...	... Virginis	9, 10	May 26	Apr. 11
VOLANS† ...	...Volantis	16	Mar. 4	Jan. 18
VULPECULA†	Vulpeculæ	13	Sept. 8	July 25

* The ancient constellation of ARGO NAVIS is now divided into the separate constellations of CARINA, VELA, and PUPPIS, but only one sequence of Greek letters is used in the three constellations.

† Constellations so marked have been added since the time of Ptolemy (about A.D. 150).

Position Angle: North Point.—*The Position Angle* of a planet's axis, or of any line on the star sphere, is its inclination to the hour circle (p. 3) passing through the centre of the object. This circle is the most suitable one for reference, as, unlike the horizon, it is stationary with respect to the stars, and being perpendicular to the horizon at the instant of culmination, can be used for finding the inclination to the horizon at other times (see diagram, p. 39). *The North Point* is the point on the hour-circle nearest the N. Celestial pole, in the field of view.

(*a*) **Double Stars.** The position angle is the angle which the line joining the components makes with the hour-circle through the brighter star of the pair; it is measured in degrees (0° to 360°) from the North Point to the fainter star, and round to the other star clock-wise, or *in the opposite direction to R.A.*

(*b*) **Sun's or Planet's axis.** The position angle is measured to it from the North Point on the disc. This varies throughout the year; but for the Sun, on the same date it is about the same every year (see the *N.A.*, and diagram on p. 40). The angle is measured from 0° to 360° for the Moon and planets, as in (*a*); but for the Sun, E. (+) or W. (−) of the hour circle.

Limb, Cusps, Vertex.—The *Limb* is the edge of the Sun's, Moon's, or a planet's disc; the *Cusps*, the horns of the crescent (less than half-illumined) Moon, Mercury, or Venus. The *Vertex*, sometimes used for occultations, is the point on the limb furthest above the observer's horizon; distances from the vertex are counted eastwards from 0° to 360°.

Opposition.—Mars, and the outer planets (p. 32), are in *Opposition* (symbol ☍), when 180° of longitude (or 12 hrs. R.A.) away from the Sun on the star sphere: this occurs annually (Jupiter, 1·1 yrs.), but biennially for Mars and most asteroids. They are then on the meridian about midnight, and nearer the Earth than when not in opposition.

An opposition is 'favourable' when the Earth and the planet are near the point where their orbits most closely approach, and as this point is always about the same longitude, favourable oppositions *always take place about the same date in the year* (given on pp. 32 to 34), and the favourableness or otherwise of any opposition can always be judged by its nearness to, or remoteness from, that date; the least favourable are six months later.

Conjunction: Syzygy.—A celestial object is in *conjunction* (symbol ☌) with another celestial body when their longitudes are the same, but the term may also denote equality in Right Ascension—as in *N.A.* 'Phenomena,' for some objects. Mercury and Venus are in *Inferior Conjunction* with the Sun, if the conjunction occurs when they are on the side of the Sun nearest the Earth: in *Superior Conjunction* if they are on the far side of the Sun, with the Sun between the planet and the Earth. The Moon is in *Syzygy* when in conjunction or opposition, *i.e.*, when New or Full.

Appulse.—An appulse is the near approach of one celestial body to another: the term is also used for approaching culmination, conjunction, &c.; as, the appulse of a star to the meridian, of the Moon to the Earth's shadow.

Orbital Motions.—The orbital motion of a planet or comet round the Sun, or of a satellite round its primary, is *Direct* when from W. to E.; *Retrograde*, when from E. to W.: similarly the seeming motions of the planets among the stars, as seen from the Earth. A planet is *Stationary* when its movement is reversing to the opposite direction.

A planet or comet is in *Perihelion* (π) when at the point in its orbit nearest the Sun; in *Aphelion*, when at the point most distant; in *Quadrature* (□), when 90° in longitude from the Sun. The Moon and the planets are in *Perigee* when at the point in their orbits nearest the Earth; in *Apogee*, when at the point most distant. *Pericentre* and *Apocentre* are the corresponding general terms for a satellite with respect to its primary: for Mars, Jupiter, Saturn, *Perimartium*, *Perijove*, and *Perisaturnium*, are used. A planet's *Elongation* from the Sun is the angular distance in degrees as seen from the Earth: the *Greatest Elongation* of Mercury and Venus is when that angular distance reaches a maximum—not necessarily the very greatest. A comet in *Recession* is moving away from the Sun, after perihelion.

Elliptical Orbits.—*The Major Axis* (symbol for semi-major axis, *a*) is the greatest length, usually expressed in Astron. Units; midway in it is the *Centre* of the ellipse. *The Minor Axis* (semi-minor, *b*) is the line drawn through the centre at right angles, the greatest breadth: *the Focus*—occupied by the Primary (p. 7)—one of two points, equidistant from the centre, such that the sum of their distances from the foci to any point on the orbit is constant, and equal to the major axis.

The Eccentricity (*e*) is the ratio, to the semi-major axis, of the focus-to-centre distance; *the Radius Vector* (*r*), the line joining the centre of a planet, comet, or satellite, to that of its primary, usually given in A.Us. *The Apsides* (plural of apsis) are the extremities of the major axis—the points of perihelion, aphelion, perigee, &c.; the *Line of Apsides*, that axis extended indefinitely.

The Nodes are the points where a planet's or comet's orbit intersects the Ecliptic on the star sphere—*i.e.*, when the object is in the Ecliptic plane:* where the object crosses from S. to N. is the *Ascending node* (☊), from N. to S. the *Descending node* (☋).

The Anomaly [*true*] (*v*) is the actual perihelion-focus-planet angle, measured in the direction of the planet's motion; the *Mean Anomaly* (*M*), that angle calculated for uniform, not actual, motion: the *Eccentric Anomaly* (μ) is derived from it, $M = \mu - e \sin \mu$.

The Elements of an Object are seven factors required to determine (*a*) Position in space of its orbit—1, the semi-major axis: 2, the eccentricity: 3, the inclination to the Ecliptic: 4, the longitude of the ascending node: 5, the longitude of the perihelion: (*b*) Position of the object at any time—6, the orbital period; 7, epoch (position at a known date); or, time of perihelion passage.

These are the *Heliocentric or Fixed Elements*—the object's relation to its primary, the Sun, ignoring other planets. *The Barycentric Elements* are those referred to the *Barycentre*, or centre of *mass* of the Solar System, instead of the Sun, which give a better average orbit—though the heliocentric one corrected for *perturbations* (disturbances) by the other planets is more accurate.

The Osculating Orbit is that which a planet or comet would pursue if, at some specified instant, the *Epoch of Osculation*, all the planets should cease to attract that body, and leave it free to move under the attraction of the Sun alone.

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* In an elliptical orbit, the node-perihelion-node angle is always less, in degrees, than node-aphelion-node, but the difference is trifling if the eccentricity is small, as in the principal planets. Also a planet attains its maximum heliocentric latitude, above the plane of the Ecliptic, halfway between the nodes—at about 90° longitude, for the principal planets, which have nearly-circular orbits.